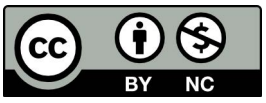
SPURA

SPIRA

DISCOVERING
MICROALGAE
THROUGH
BIODESIGN

Degree in Industrial Product Design | A.A. 2022/2023
Department of Architecture
Alma Mater Studiorum University of Bologna

Supervisor: Prof. Michele Zannoni
Correlators: Prof. Marco Mancuso - Akarsh Swamilingappa Annaiah
Candidate: Nicolò Baldi | 970240



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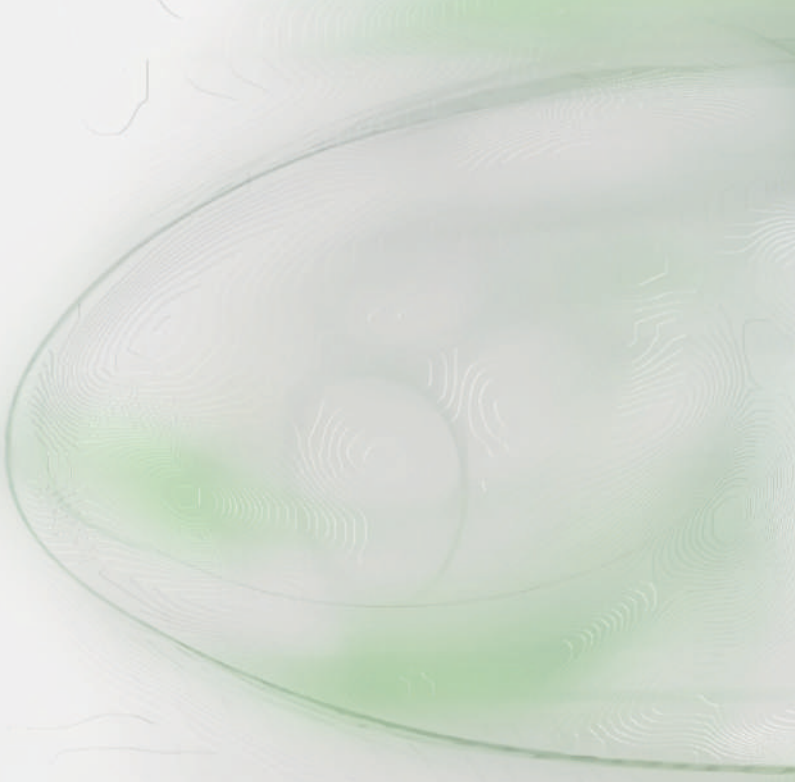
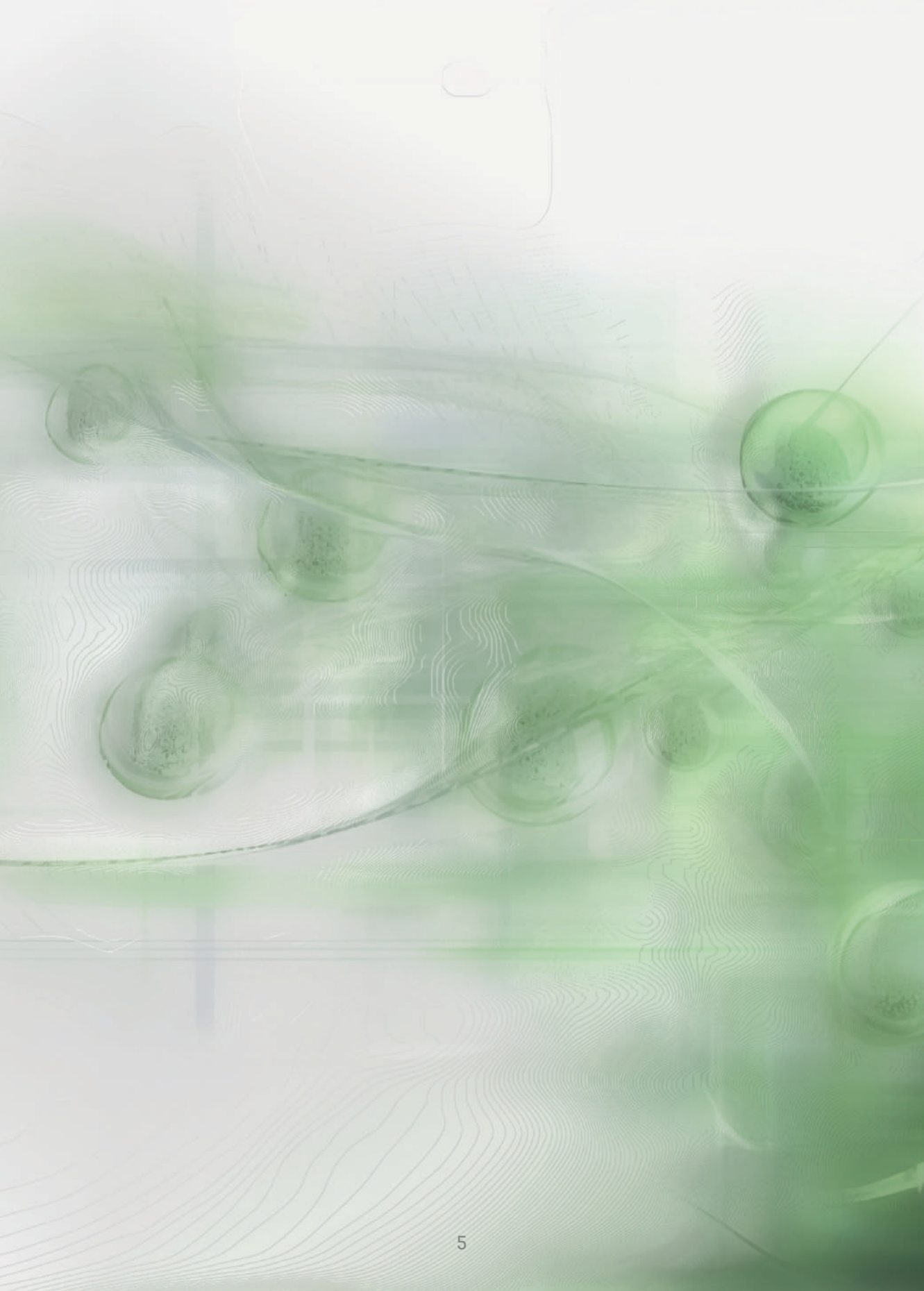
00. PREFACE





00. PREFACE

A polypropylene garden chair will live much longer
than you and me.

Statements such as these put us in the position of reconsidering what our role on this biosphere is as living beings, since they stimulate us into thinking on time scales much broader than those that dictate our everyday life. The designer's position is delicate in these terms, being the figure involved and responsible for the ideation processes whose consequences will eventually be assimilated into the 'real world'. It is important to emphasise that no project is exempt from these consequences, be they social, economic, political or environmental. And if this is true for every designer in the professional sense of the term, then it also extends to every individual, since in our lives we are creative beings shaping our own present and future.

Despite their omnipresence, the evaluation of these criteria is often incomplete or even absent. In fact, the most common and significant error lies in thinking that these consequences are exclusively at the human level. This ideology is part of the anthropocentric view of reality, an interpretation of the surrounding world as presence at the sole service of human specie. But where does this ideology come from? And above all, why is it erroneous? Tracing the origins of anthropocentric thinking is a broad and debated path, but it is a concept well summarised by Timothy Morton, the philosopher who coined the term that best represents our contemporary world: hyperobject. Hyperobjects denote entities of such spatial and temporal dimension that they envelop everything around us and disrupt our very perception of what an object is.
Global warming, the pandemic crisis and capitalism are examples of hyperobjects, as they dramatically confront us with phenomena that are too large, complex and diffuse for the individual to comprehend. [1]

> "We always used to think that the U-shape of the drain was a convenient curvature capable of taking whatever was dumped into a completely different dimension, an elsewhere, leaving everything clean

> here on the surface. Now we know how things really are: instead of in the land of elsewhere, the waste ends up in the Pacific Ocean in a sewage treatment plant. Knowledge of the hyperobject-earth and the hyperobject-biosphere confronts us with viscous surfaces from which nothing can be pulled away by force; there is no elsewhere on this surface, neither here nor anywhere else."
> [1][T. Morton - Iperoggetti (2018) - (p.48)]

Morton himself defines architecture and design as tools in the service of the notion of 'elsewhere', and similar criticisms had already been highlighted by two well-known designers as early as the 1970s: Victor Papanek and Tomàs Maldonado.

> "It is not easy to make a 'clean sweep' in the universe of objects. It seems to be easier to produce an object than to make it disappear: the most refined technical tricks only help to a certain extent. One can attempt to reduce its size, to compress it, to dismantle it, to fragment it, to reuse it, to partially recover it as raw material; in spite of all this, more or less tangible residues always remain. In some cases, these residues become part of the 'population of pollutants and artificial erosion factors'. This population does not occupy habitable spaces, but contaminates them, corrodes them, deteriorates them, dissolves them, withers them: finally, it makes them humanly uninhabitable."
> [2][T. Maldonado - La Speranza Progettuale (1971) - (p.79-80)]

> "As design problems have become increasingly complex with the global proliferation of technology, human beings have become increasingly alienated from direct contact with the biological environment."
> [3][Victor Papanek - Design for the Real World (1971) - (p.188)]

It seems that any attempt to artificially optimise the environment around us backfires, causing exponential and irreversible damage. Seeking solutions to the climate crisis is frustrating, humiliating, because it evokes feelings of profound impotency and forces us to question every principle that is firmly anchored in our logic.

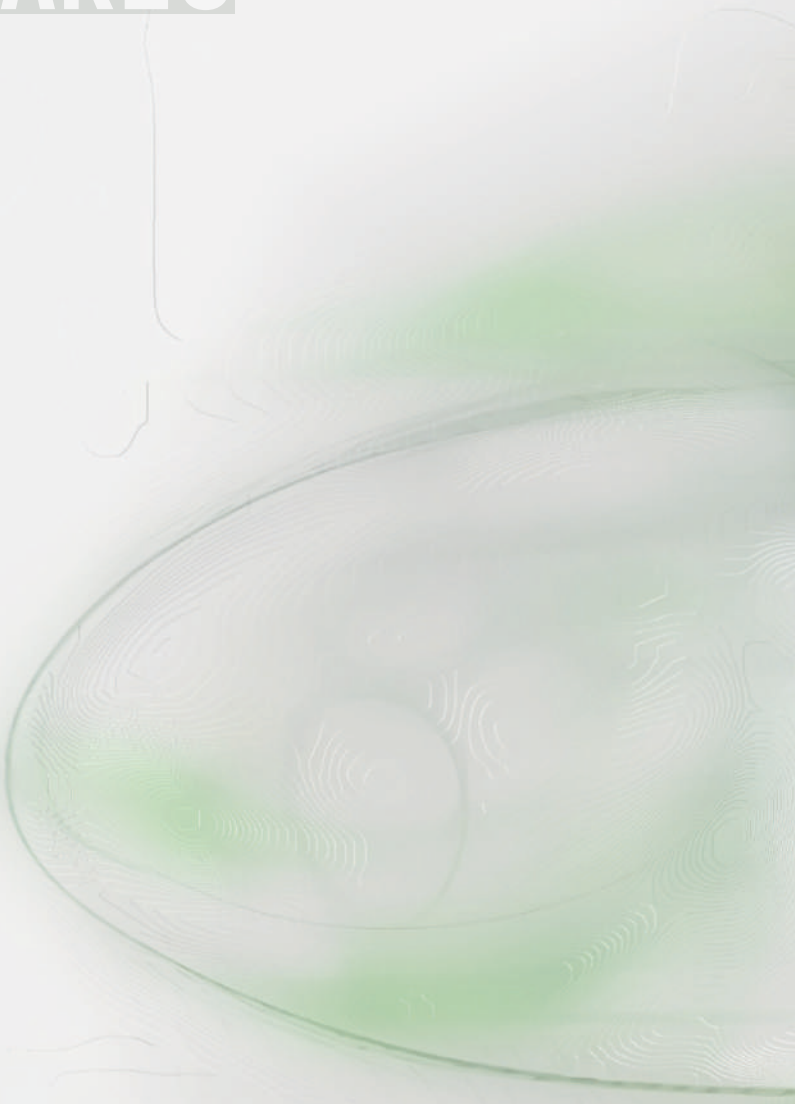
00. PREFACE

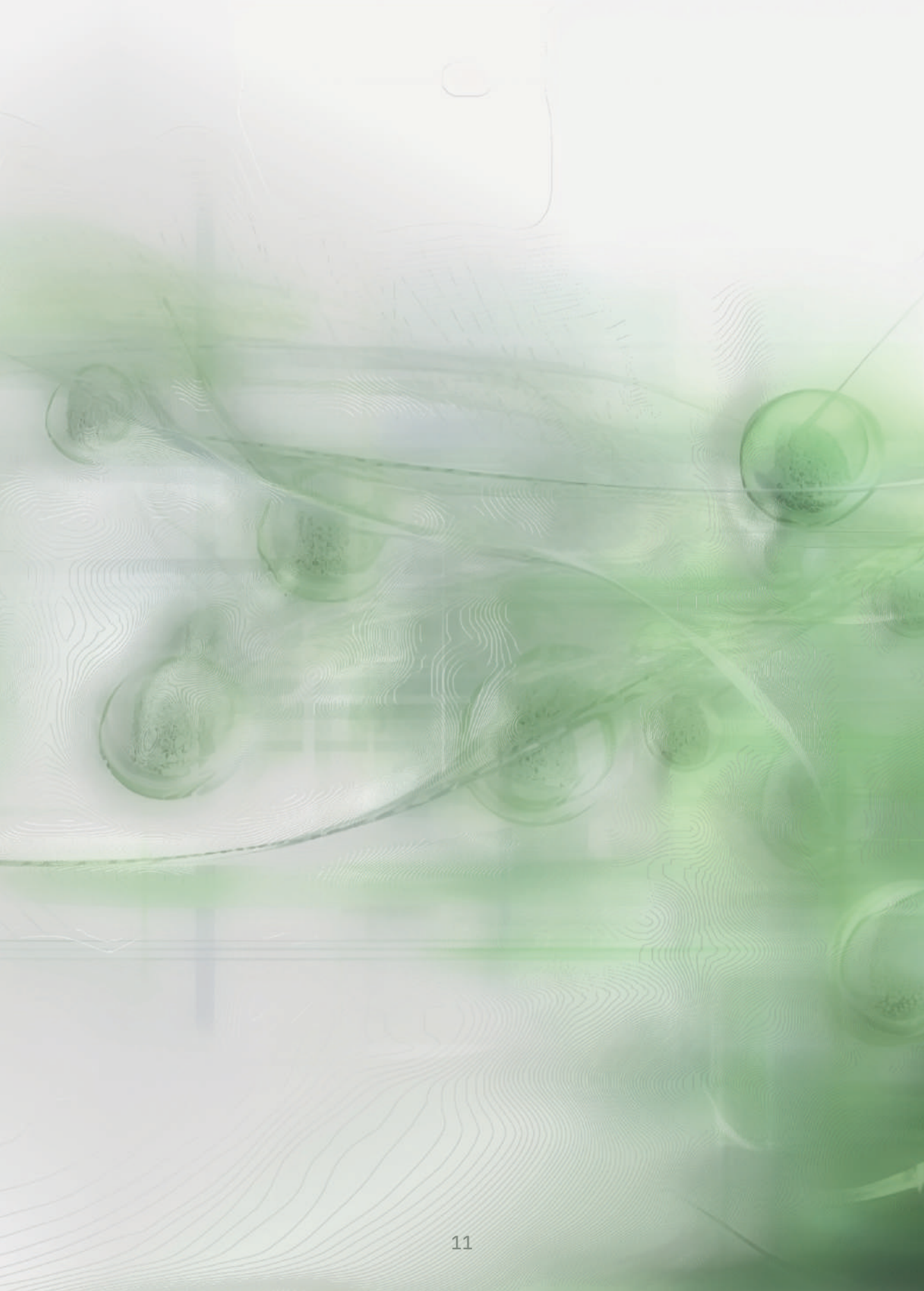
> "I find it provocative to make room for all those beings I have always tried to ignore. Who has not been bored at least once by the ecology debate?"
> [4][Timothy Morton - Humankind (2017) (p. 88)]

The climate crisis is merely the direct manifestation of our inability to acknowledge and deal with our interdependence with the natural world. This species self-isolation is reflected in the common notion that human beings live outside of what we conceive of as 'Nature', the image as romantic as distorted of a distant and uncontaminated place that lives independently of human action. The sharp boundary between human and non-human, artificial and natural is an illusion: 'Nature' is not an elsewhere, but the reality in which we live. [5]

These complex relationships are often ignored by the world of design. Our choices, the technologies we develop and the objects we design do not exist in a void, but are an integral part of the Earth's wider ecosystem. This is why it is urgent to reconsider the way we design, produce and consume. We need to shift away from anthropocentrism and adopt a more ecocentric perspective that recognises the intrinsic value of biodiversity and the entanglement between human and non-human.

01. SCENARIO





01. SCENARIO

The context in which SPIRA is embedded is a fragile world marked by deep wounds, but in which design itself stimulates new unexpected alliances and breaks down contemporary complexity. In fact, it is no longer only concerned within aesthetic or functionality; rather, it behaves like a process of genetic evolution, where each design choice is driven by an imperative of survival and resilience.
This design also promotes collaboration to address generalised challenges, taking advantage of interdisciplinary approaches to combine the best of skills from different fields.

One of the most significant examples of interdisciplinary approaches is biodesign, which combines natural sciences, design, engineering and other disciplines to design inspired by or employing natural processes. In addition to the practical benefits of employing both artificial and biological techniques, its peculiarity is that it promotes solidarity between different forms of life, emphasising respect and cooperation with them rather than domination and control. Biodesign and bioart, moreover, are proving to be the fundamental vector for the convergence of the worlds of scientific research and common knowledge. This is because aesthetic sensitivity and narrative persuasion are essential elements to allow the scientific niche to emerge from its cage, so as to be more perceived in the social tissue. [6]

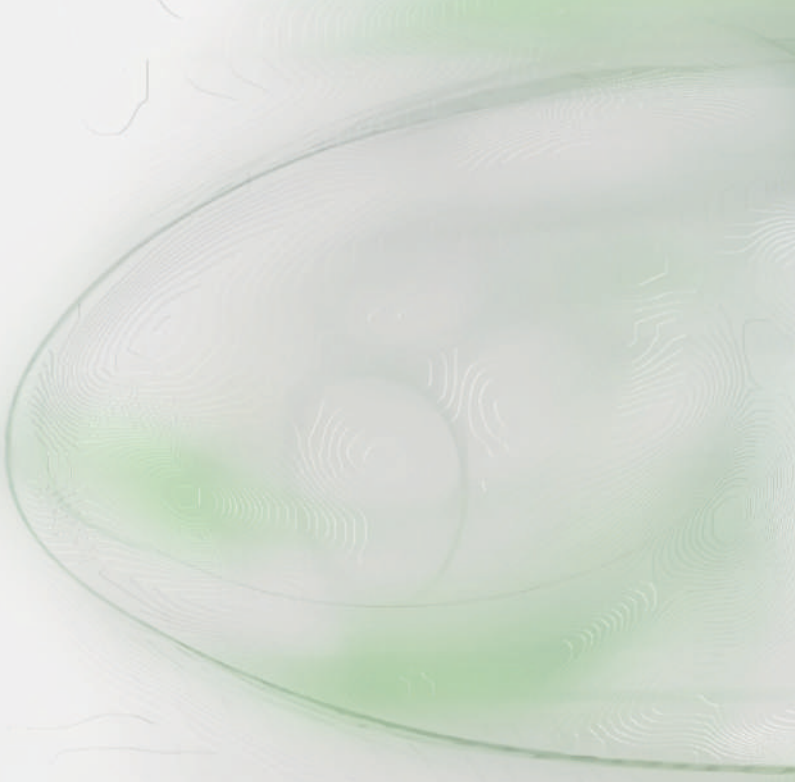
> “The current dissemination of artistic-scientific works takes place at a time when the relationship between art and science has reached a critical juncture. This is characterised by a generalised distrust of science - due in part to its close relationship with capital - and, at the same time, by the urgent need to defend expert knowledge in the context of 'fake news' and, in particular, to uphold the truth of environmental science against climate change deniers.”
> [7][Joanna Page - Decolonizing Science in Latin American Art (p.6)]

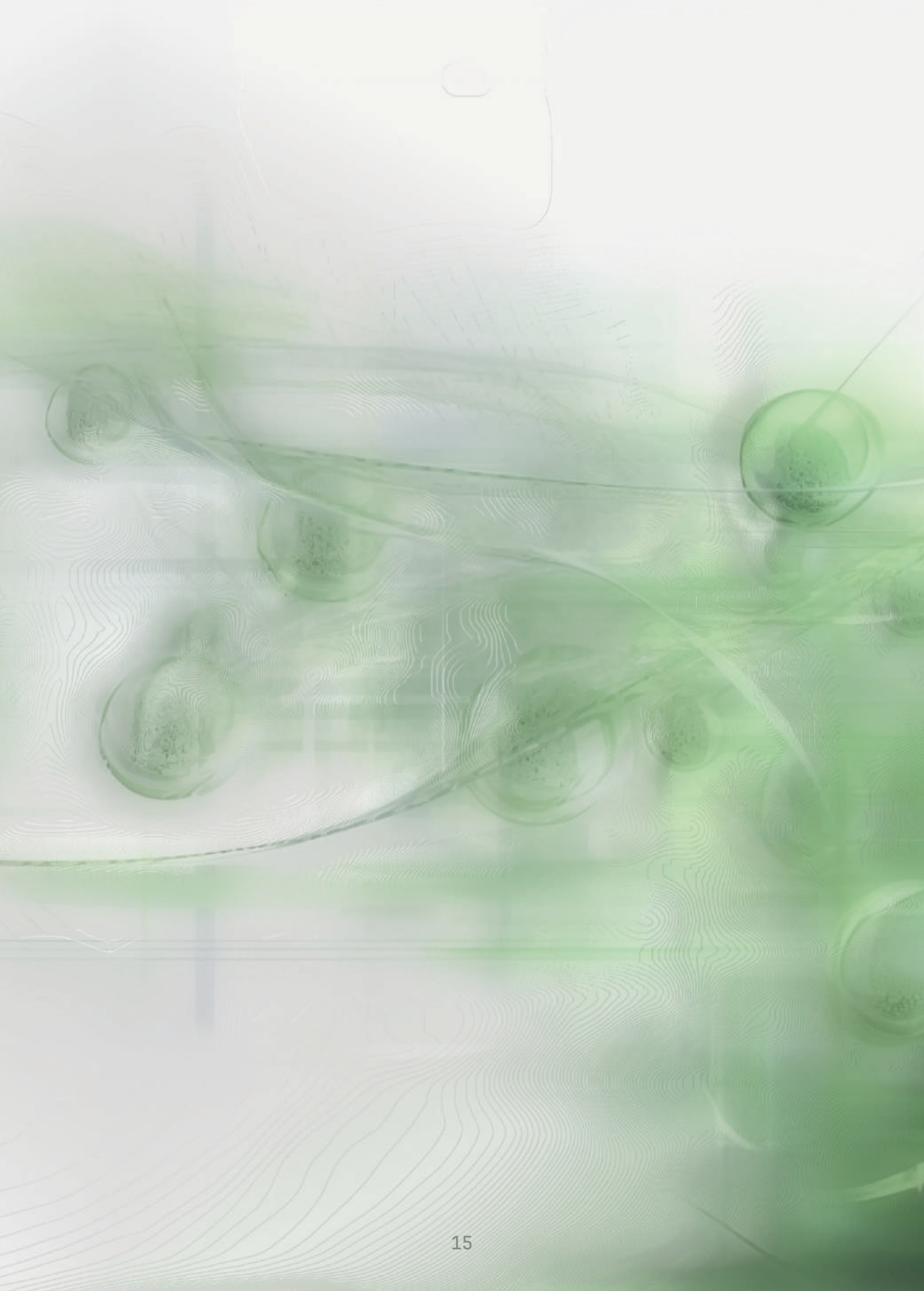
The application of more creative approaches in the scientific landscape -and vice versa- also helps to stimulate transversal research that combines technical efficiency with strong ethical and communicative values. Examples of this are exhibitions such as 'Broken Nature: Design Takes on Human Survival' at the 22nd Milan Triennale, workshops such as the MediaMatic in Amsterdam, and the works of artists such as Gilberto Esparza and Ivan Henriques.

But it is not only projects that follow a 'top-down' logic that emerge from this context. The passivity of institutions and general dissatisfaction have led to another strategy proving to be fundamental in facing these challenges: the Do-It-Yourself (DIY). In fact, DIY emphasises the importance of individual empowerment and education: the goal is to distribute tools and knowledge required to make conscious and sustainable decisions, both in the design framework as in everyday life. And while the meaning on "doing it by yourself" may seem exclusively singular, it is important to emphasise that DIY environments are always collaborative. This is because they are possible precisely because of the sharing of information and knowledge through open-access software, communities, online libraries, tutorials and FabLabs; all channels that provide an unprecedented ability to take a proactive role in finding alternative solutions.

The potential in combining these values offers unexplored horizons, and the case studies that follow offer a preview of how we might reinvent our approach to design, today and in the immediate future. Similarly to the biological world, where ecosystem adaptation strategies begin with small-scale systemic changes, these independent design cases arise to counter the inefficient ecological and political decisions that define our present. They demonstrate how it is possible to take advantage of science and bring it outside its academic bubble, to distribute and understand the knowledge that could make us less incapable in front of imminent challenges.

02. CASI STUDIO





02.1 HANG SU - PHYTOSPHERE

Phytosphere is a speculative design project that represents an 'artificial ecosystem', a symbiotic environment where different species of organisms and machines work together for their sustenance.

The six cases, each composed of an organism and artificial mechanisms, are coordinated by a central computer that provides instructions to each hybrid to optimise the conditions of another. In particular, the 'Microalgae Hybrid' consists of a Chlorella microalgae culture and a density sensor.
When this detects a culture density higher than a certain value, it flushes sediment into the other cases in order to fertilise the other organisms. The project uses the speculative design narrative and biodesign approach to send a powerful message: collaboration between humans, non-humans and technology is possible. [8]

Figure 1: Phytosphere.

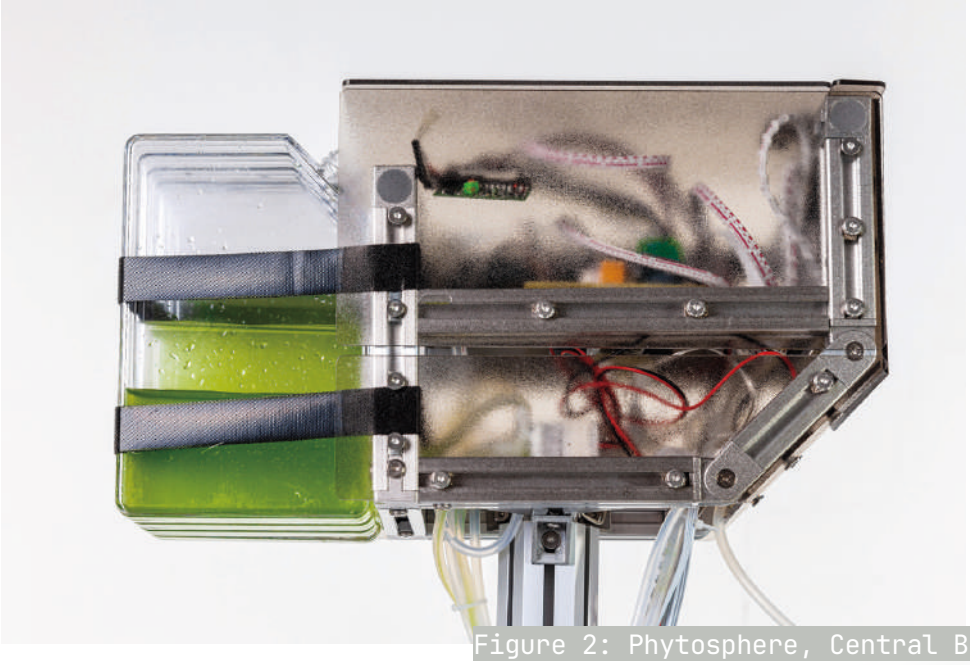


Figure 2: Phytosphere, Central Brain.

02.2 ECOLOGIC STUDIO - BIOBOMBOLA

EcoLogic Studio is formed by Claudia Pasquero and Marco Poletto, two ambassadors of biodesign and of the application of microalgae in architecture and design. At this time, BioBombola is the only photobioreactor designed by a professional studio with the aim of introducing the cultivation of microalgae for domestic use. Although it is not yet on the market, BioBombola unquestionably remains a pioneer and unique benchmark in the field, essential to show both its potential and its limits.

Its creators claim that BioBombola is capable of absorbing the carbon dioxide equivalent of two young trees, while generating oxygen equal to seven indoor plants, all in a 1 metre high glass structure. [9]

Figure 3: BioBombola with a Spirulina culture.

02.3 ECOLOGIC STUDIO - PHOTO.SYNTHETICA CURTAIN

EcoLogic Studio also presents an architectural-scale version of the photobioreactor principle. The most important feature of the project lies in the type of material used: for the first time, it is a bioplastic film, and not a rigid structure. This choice allows greater lightness and light diffusion, while reducing bulk and costs.

This strategy is used to provide a curtain system designed for urban space, so that the photosynthetic properties of microalgae can be even more effective.
Photo.Syntetica Curtain was presented in Dublin during the 2018 Climate Innovation Summit, with a structure consisting of 16 modules of 2x7 metres, and another modular version of the project was instead set up in Helsinki in 2019.
Although the project is extremely cutting-edge, some details and information are not available: for example, it is not specified how the circulation of microorganisms takes place or how biomass can be collected. [10]

Figure 4: Photo.Synthetica Curtain (Dublin, 2018).

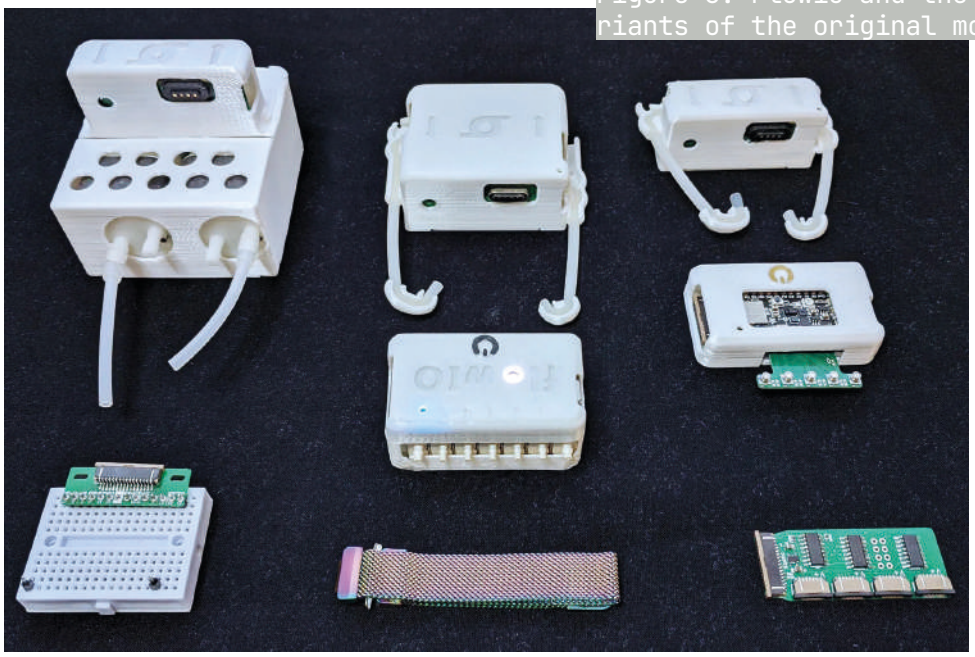
Figure 5: Photo.Synthetica Curtain (Helsinki, 2019).

02.4 SOFTROBOTICS.IO - FLOWIO PLATFORM

The MIT Media Lab's 'Flowio' platform was created with the aim of spreading and stimulating interest in soft robotics, i.e. the design of robots using inflatable and flexible materials.

The toolkit can be requested free of charge by communicating the design intentions, but on the website there are also all the indications for making your own version. This section of the project is very in-depth, showing tutorials, files for 3D printing and codes, but also hypothetical costs and timeframes for realisation. The attention placed in this direction underlines the desire to transfer knowledge of a discipline that remains still largely unexplored. [11]

Figure 6: Flowio and the variants of the original module



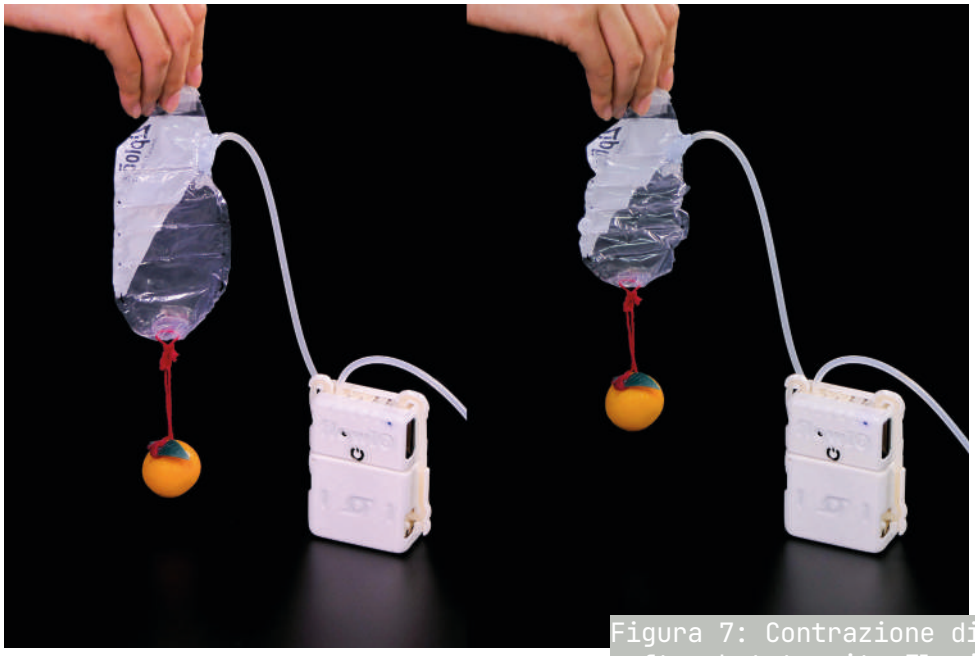
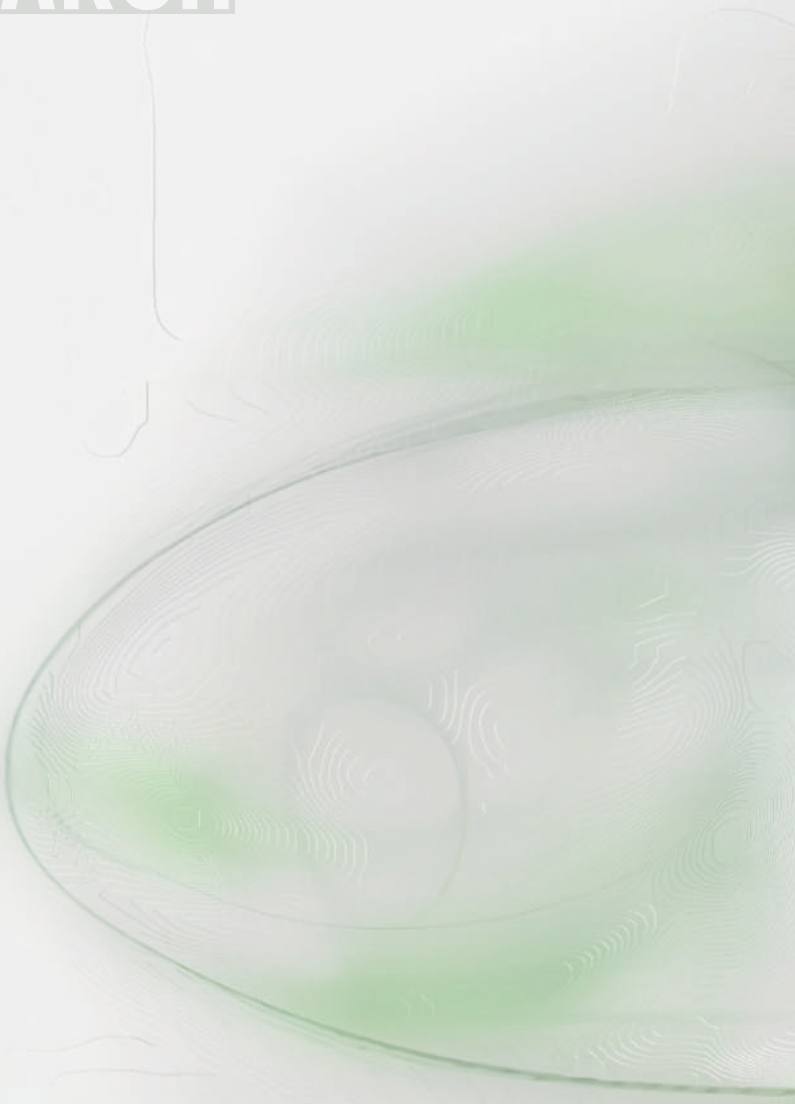
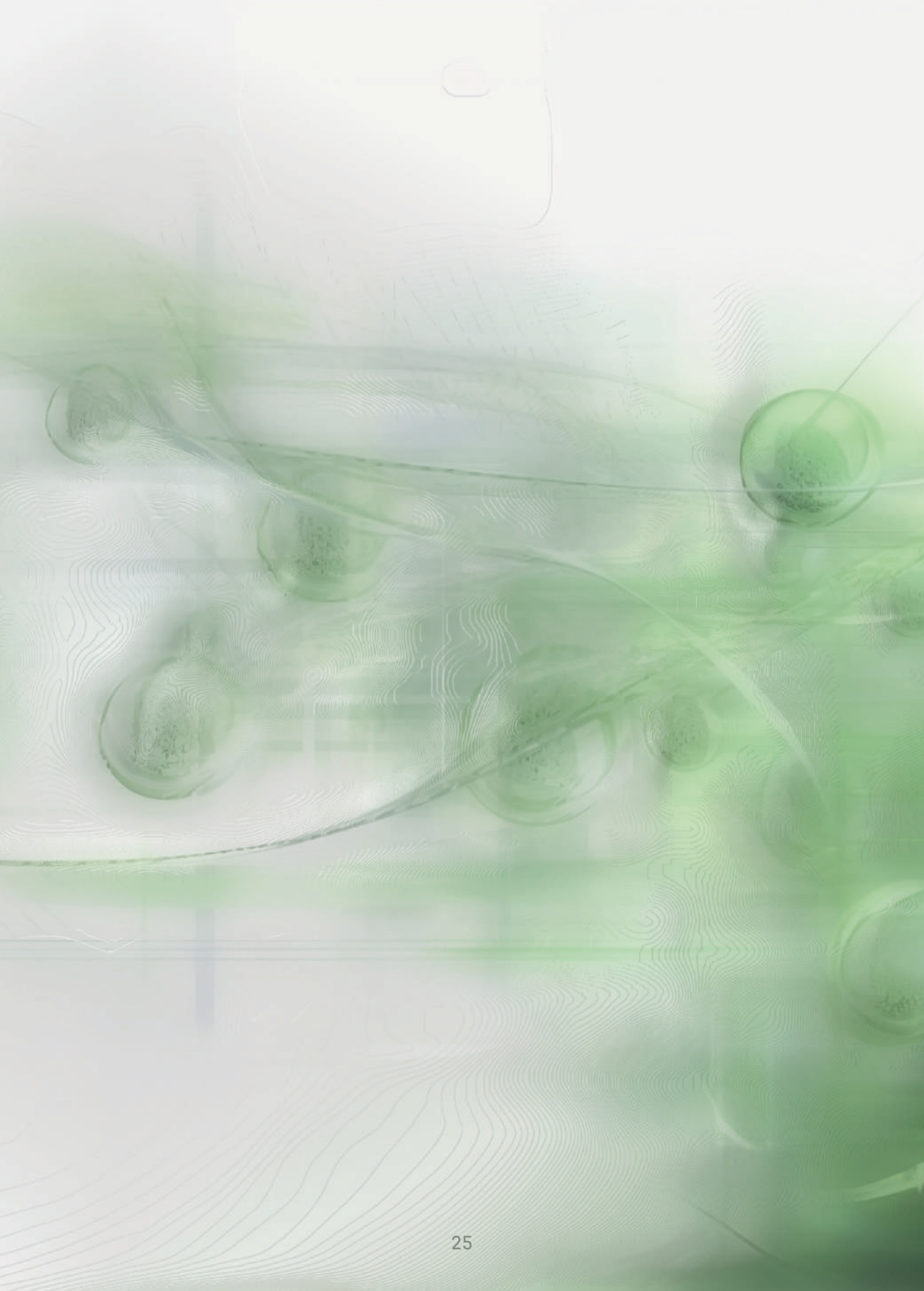


Figura 7: Contrazione di un soft robot tramite Flowio.

03. RESEARCH





03.1 INTRODUCTION

Cyanobacteria are among the oldest life forms on Earth's surface. In particular, they were the first photosynthetic organisms, playing a primary role in the GOE -Great Oxygenation Event-, a 10-million-year-long process that led to the Earth's oxygenation and subsequently the emergence of complex life forms. [12]
It seems somehow ironic to think that today, billions of years later, the very descendants of these primordial organisms can provide an invaluable insight to species that is indelibly changing geological history.

Microalgae and cyanobacteria -grouped under the name of phytoplankton-, produce 60-75% of the oxygen that we and other animals breathe, more than any other plant distribution on land. They form the basis of the aquatic food chain and their incredible biodiversity -an estimated 72,500 different species, twice as many as plants- makes them widely distributed in different ecosystems and a complex and largely unexplored field of research. [13][14]

However, human and microalgae history only intersect around 1300, in central Mexico, when the Aztecs began collecting and consuming a green substance growing on the surface of the alkaline lake Texcoco: Spirulina. The Aztecs recognised the nutritional potential of this foodstuff, and after drying the harvest, they baked a flat cake called 'tecuitlatl', which they often consumed on the occasion of great physical efforts. However, during the 16th century, the 'green slime' was not appreciated by the Spanish colonists, who therefore drained most of the local lakes, leading to the almost total disappearance of this practice and related knowledge. [15]
Research and commercialisation of microalgae only resumed

from 1970 onwards, and thanks to advances in biotechnology, interest in these organisms has been on a growing trend. Since then, microalgae and their biomass have been studied for their nutritional, pharmacological and photosynthetic abilities, as well as their applications as biofuels and fertilisers.

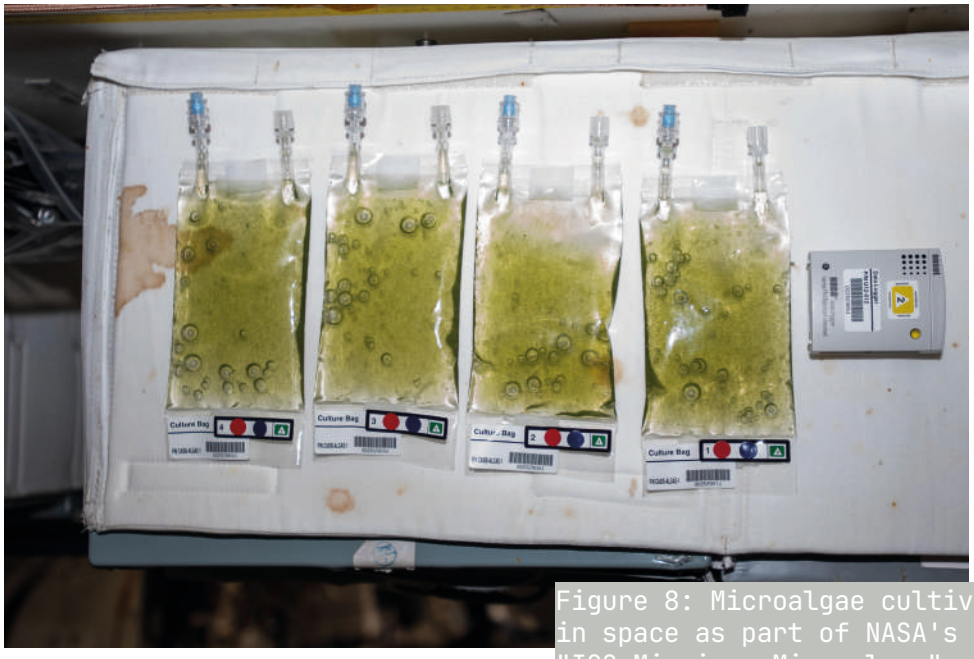


Figure 8: Microalgae cultivation in space as part of NASA's "ISS Mission: Microalgae" programme, 2019

Today, however, it is one characteristic in particular that stands out above all others: the ability to absorb carbon dioxide. Since the industrial era, the concentration of CO2 in the atmosphere has done nothing but increase: whereas between the years 1000 and 1750 the concentration was around 275 ppm (parts per million), in the 20th century it was 295 ppm and in 1950 310 ppm. This trend is described by the Keeling Curve, which in 2015 recorded a value above 400 ppm for the first time in at least 800,000 years. [16]

In July 2023, the average CO2 concentration in the atmosphere is 421.76 ppm. [17]

At this rate, it is estimated that by the end of the century, atmospheric CO2 may exceed 1,000 ppm, a value at which human cognitive abilities collapse by 21% and which is already recorded in closed or poorly ventilated environments such as homes or offices. [16] The increase in CO2 is the main cause of anthropogenic global warming, 91% of which is due to the use of fossil fuels and 9% to land use; moreover, carbon dioxide is highly durable, so much that even if its emission were to be stopped tomorrow, the effects of its presence would continue for hundreds of years. [18][19]

The ability of microalgae to absorb this gas could play a key role in adapting to the major changes we face today and in the future. [20] Their elementary cell structure allows them to be much more efficient photosynthetic organisms than plants. They can grow in salty, fresh, highly alkaline water and purify waste water, so that they can be cultivated without using land area. [13]

The following research documents an attempt to dive into first-hand knowledge of these organisms at the borderline between DIY and scientific research.

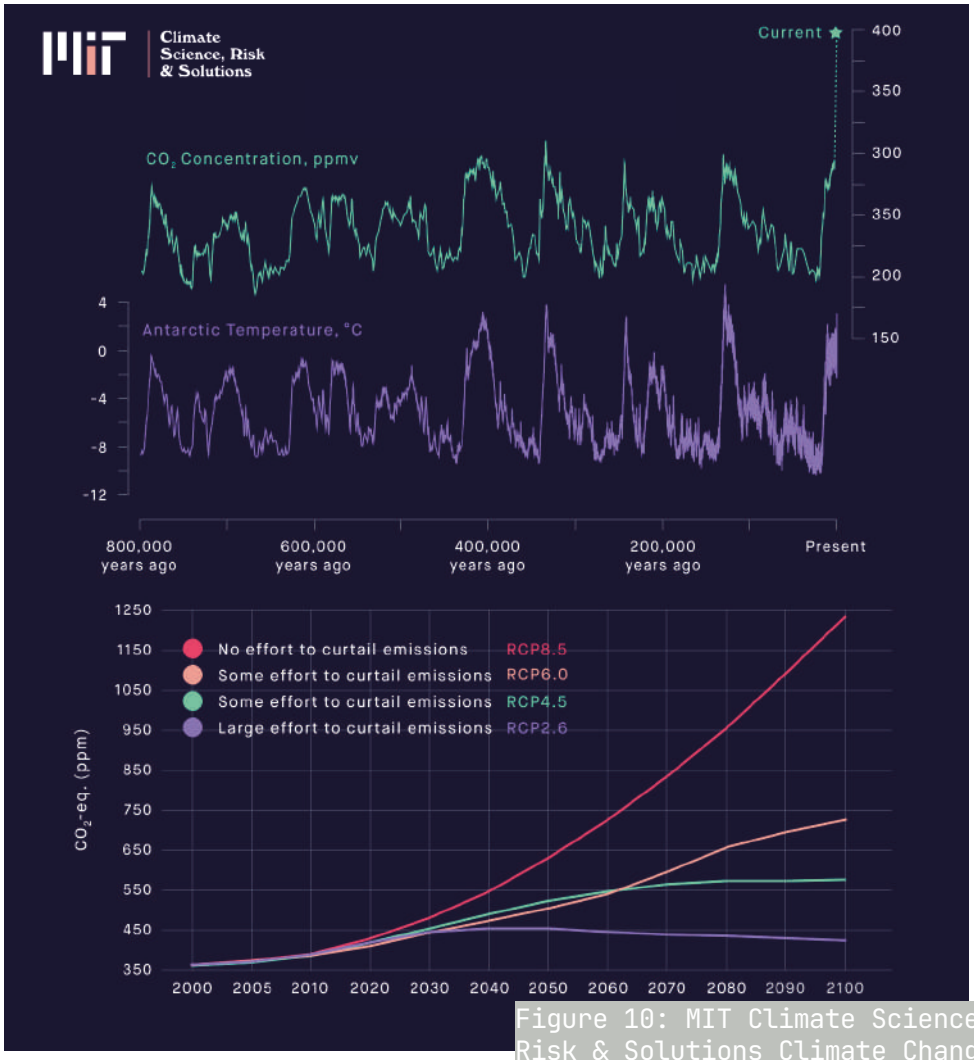


Figure 10: MIT Climate Science, Risk & Solutions Climate Change Report (2023).

03.2 STATE OF THE ART

The cultivation of microalgae takes place within structures called photobioreactors, characterised by inputs -light, carbon dioxide, nutrients- and outputs -oxygen, biomass-.[21]

Photobioreactors are classified into open, pond-like, and closed, transparent structures where communication with the outside air occurs only through small channels. In the course of this research, attention will only be focused on closed photobioreactors. [22] While open photobioreactors allow mass and less expensive cultivation, closed photobioreactors provide a more controlled and safe environment for the growth of microalgae, offering greater protection from pathogens.

However, the greatest criticality faced by closed photobioreactors is the cost of production and maintenance.
In fact, the use of a closed photobioreactor often coincides with the use of artificial light - although this is not mandatory - and pumps to inject carbon dioxide into the culture. [23] These factors tend to make large-scale closed photobioreactors inefficient both in terms of energy and for a carbon-negative system -that is, capable of absorbing more CO2 than is needed for its production and maintenance-.
This last issue is usually ignored by large-scale cultivation as it does not produce any value for the economic system of the activity.

Despite this, microalgae and their biomass have multiple commercial applications, which are described by the diagram on the following page. One particularly promising area of study involves third-generation biofuels made from the microalgae biomass, as the 10-45% oxygen they contain is released during their combustion, as opposed to conventional oil-based fuels, which contain no oxygen at all. [24]

Figure 10: Closed photobioreactor cultivation, ALG-AD Research, 2020.

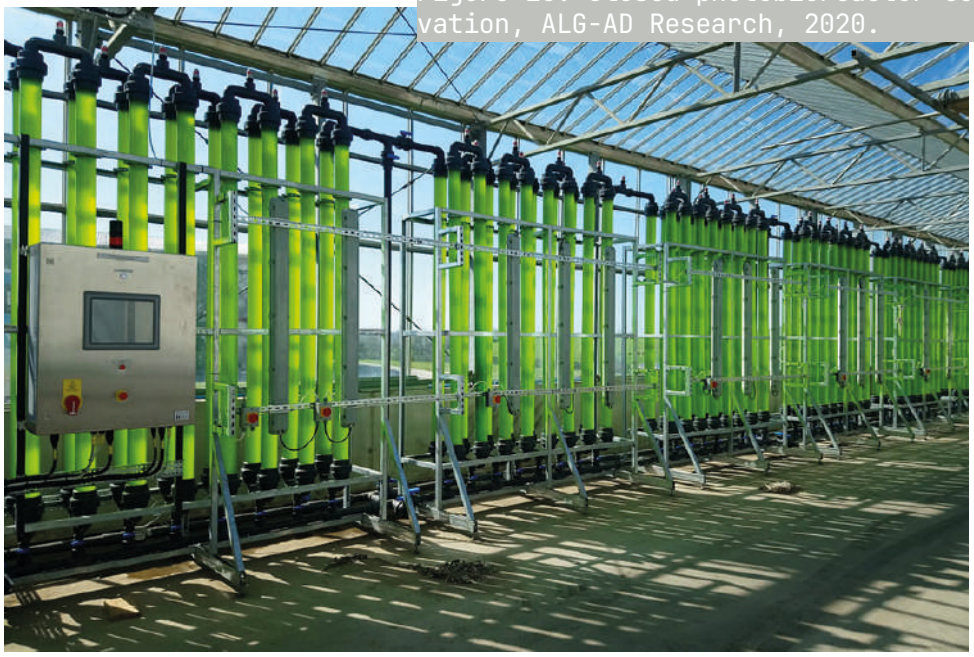


Figure 11: Open photobioreactor cultivation, Merredin, Australia, 2015.

03. RESEARCH - STATE OF THE ART

Research on microalgae is both promising and lacking in attention. In fact, one only has to peek into the field to realise how much both the scientific community and individuals are calling for more interest in these organisms and their properties.

While studies emphasise the need to reduce costs and promote the use of microalgae in public and private spaces in order to spread knowledge, online there are numerous DIY projects on the subject; it is a very rare case in which the number of independent projects even exceeds those available on the market. [25][26]
However, despite the relative abundance of information, there is a lack of reference points and guidelines for those wishing to delve into this practice, remaining a niche area unknown to most.

This issue also plays a key role in relation to design and architecture, as the applications of biomass in these areas are not yet sufficiently explored, unlike other more established sustainable systems such as solar or eolic energy. This limits the idea of a truly committed design in finding sustainable solutions and restricts it to only market trends.

Furthermore, design and architecture can be unique tools for increasing public awareness by exploiting their own aesthetic and communicative strategies. [26]

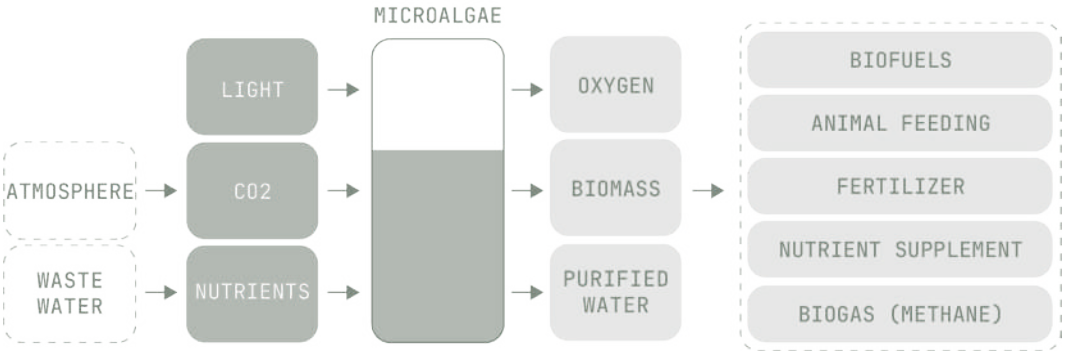


Figure 12: Microalgae processing [24].

03.3 MATERIALS AND METHODS

PRELIMINAR PHASE
Two of the most widely distributed microalgae on the market have been used for the culture:

- ARTHROSPIRA PLATENSIS (SPIRULINA): Arthrospira platensis is a cyanobacteria, commonly recognised as blue-green algae named Spirulina. It has a multicellular structure (50-500 microns) that assumes a spiral shape, from which it takes its name. It grows between 25 and 35 °C, and the optimum PH is between 8 and 10.
- CHLORELLA VULGARIS: It is a unicellular green algae (2-10 microns). It can survive at temperatures ranging from 5 to 30 °C, and the optimum PH is between 7 and 8. [23]

The two samples of 200ml each were purchased online and stored in the refrigerator for a two-week period before starting the culture.

In the meantime, the designed photobioreactor was set up: an aquarium divided by an acrylic sheet to house both species in two cases with a capacity of 6L each. In order to have a more stable culture, it was decided to provide artificial lighting for the microalgae: a series of LED strips were therefore installed considering 6000K as the ideal light temperature for growth. [21]
In the rear compartment, two 6V pumps are used, which supply atmospheric carbon dioxide to the microalgae via some 4mm aquarium tubes; at the end of the tubes, airstones are installed, diffusers that nebulise the incoming air to encourage the absorption of CO2 by the microalgae. [23]

Finally, an Arduino UNO and a DHT11 sensor are used to monitor the internal temperature and humidity values, displaying the data in real time on an LCD monitor located in the front panel of the aquarium.

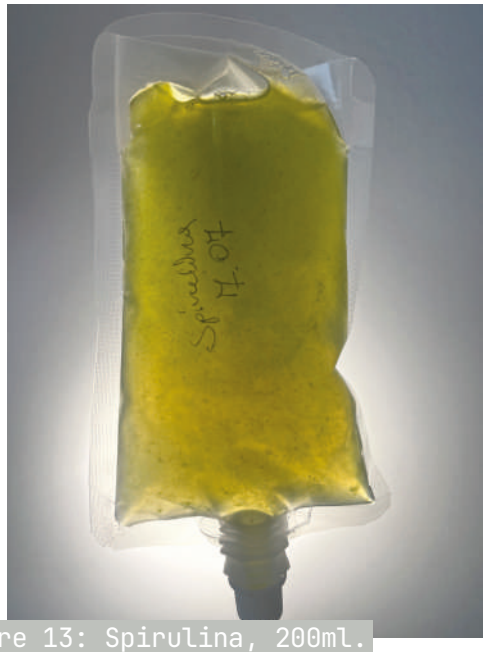


Figure 13: Spirulina, 200ml.

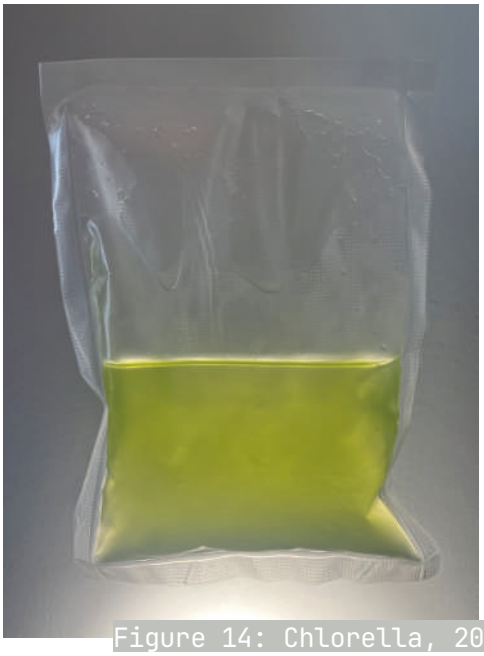


Figure 14: Chlorella, 200ml.

NUTRIENTS

Once the structure has been assembled, the preparation of the culture is next. First, the inside of the aquarium is sanitised with a food surface cleaner and washed several times to remove residues.The preparation of the necessary nutrients follows: the ingredients of 'Zarrouk's Medium', the most widespread culture medium for microalgae, are chosen and a solution of 3L each is used. [28]

INGREDIENTS	g/L	g/3L	SPIRULINA	CHLORELLA
NaNO3	2.5	7.5	7.53	7.61
K2HPO4	0.5	1.5	1.56	1.54
K2SO4	1	3	3.13	3.08
NaCl	1	3	3.04	3.05
MgSO4.7H2O	0.2	0.6	0.61	0.62
CaCl2.2H2O	0.04	0.12	0.12	0.12
FeSO4.7H2O	0.01	0.03	0.03	0.03
EDTA	0.08	0.24	0.24	0.25
NaHCO3	50.4	50.4	50.22	50.11

Table 1: Medium's ingredients with their respective amounts.

The ingredients are weighed and mixed appropriately and then poured into the aquarium.

The microalgae are removed from the refrigerator and wait for them to adjust to the ambient temperature before pouring them into their respective cases. At this point, the top cover is

placed and the living conditions are checked: temperature and pH value. The latter is measured using common litmus paper and adjusted with sodium bicarbonate (NaHCO3) -to raise the pH- and sulphuric acid (H2SO4) -to lower it-.

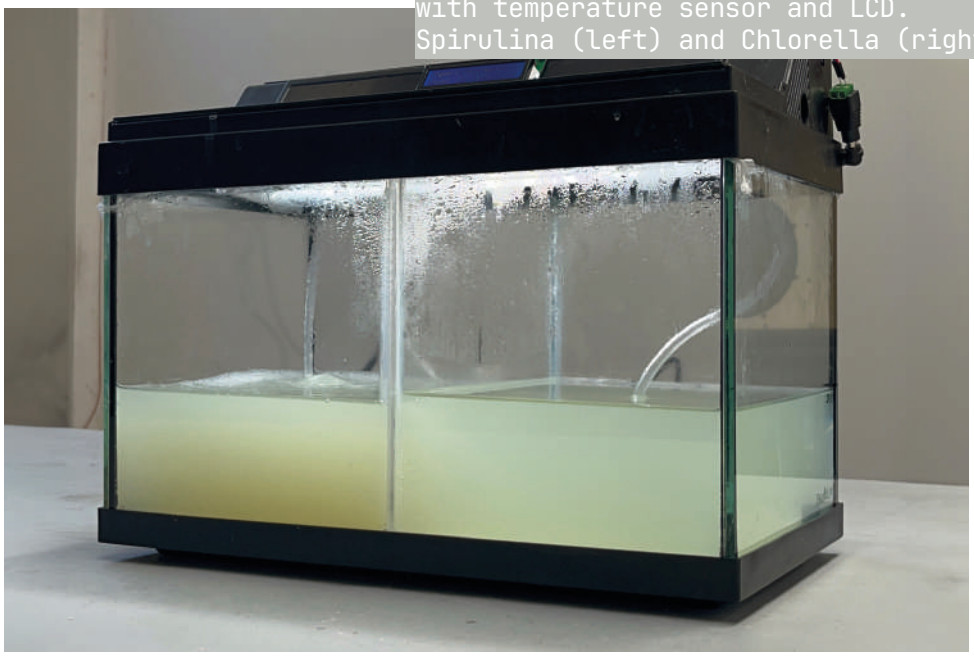
Figure 15: The nutrient salts required for the culture medium.

CULTURE

From the very first days of cultivation it is noticeable that the Spirulina takes on an unusual yellowish colour, which is because the culture was actually received already partially damaged due to the excessive heat received during shipment. This is why Spirulina will take longer to adapt to the conditions in the photobioreactor and take on its typical blue-green hue. Chlorella, on the other hand, gradually becomes denser and greener, until after less than a week the first sediments of biomass begin to be seen at the bottom of the theca. After about 10 days, Spirulina also finally begins to revive with a light green colour. Once a week, nutrients are supplied regularly in a 500 ml solution by mixing the culture to improve the distribution in the volume of the theca. A tank with a new healthy Spirulina culture is also added and upgrades are made to the photobioreactor to optimise its functionality and energy efficiency.

First, the electronic components are reduced in size, so the Arduino UNO is replaced by an Arduino NANO with a WiFi module to transmit data to the Arduino IOT application.
In addition, the LCD screen is replaced by an OLED which, by means of a button on the side of the structure, displays the project logo, temperature and humidity in real time and a graph showing the temperature trend over the last 12 months.
It is then chosen to make use of a single pump, which is more than sufficient to supply carbon dioxide to each display case. In addition, it is ensured that a single 5V power supply can power the LEDs, the pump and the Arduino NANO, considerably improving the system's power consumption.

Figure 16: The photobioreactor equipped with temperature sensor and LCD. Spirulina (left) and Chlorella (right).



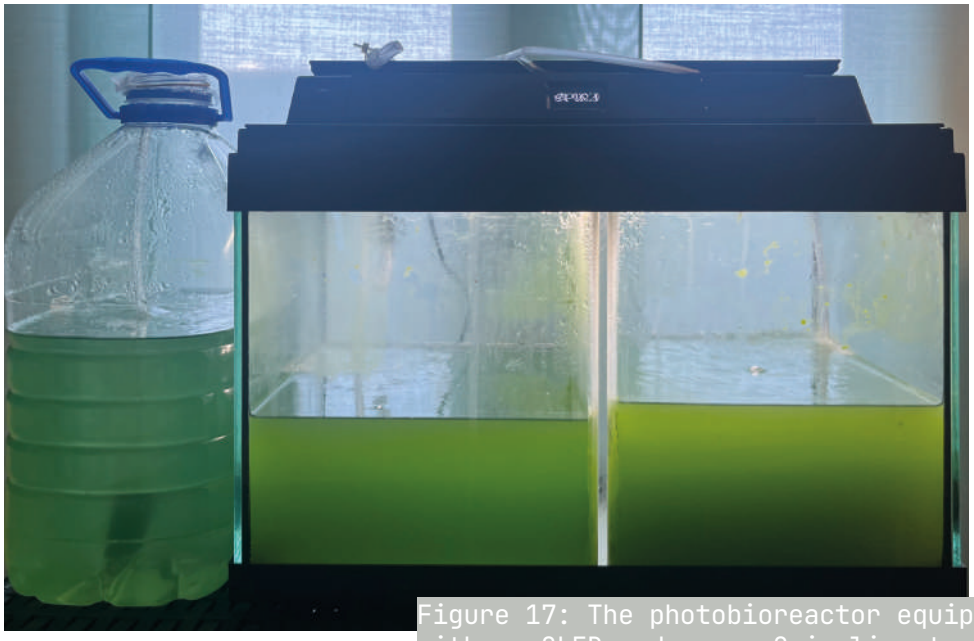
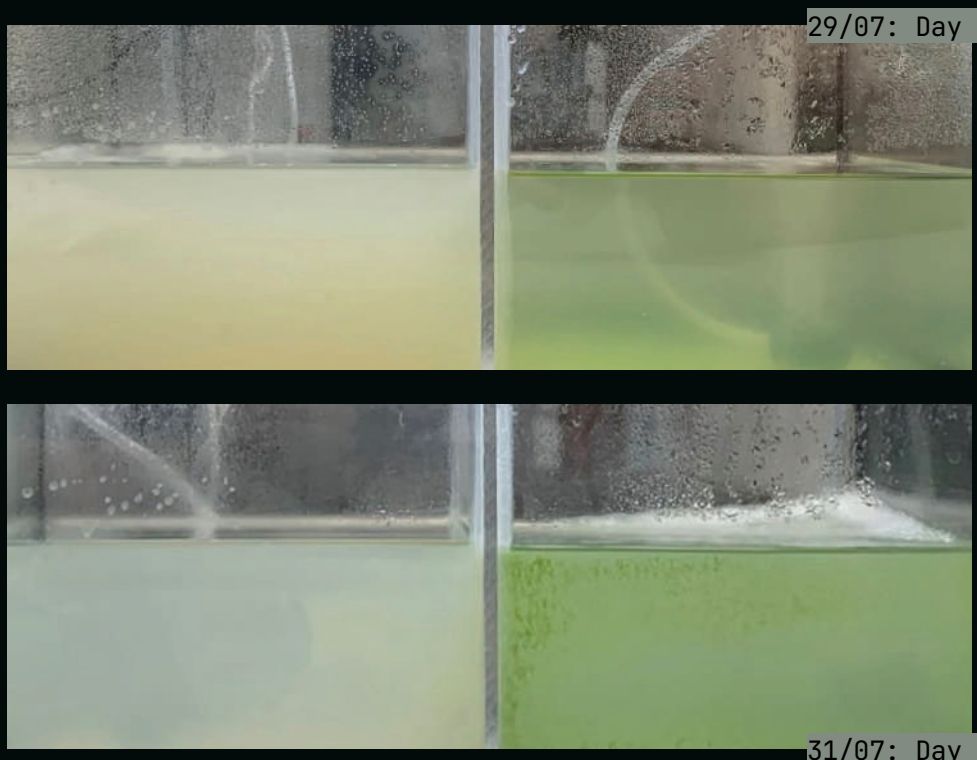


Figure 17: The photobioreactor equipped with an OLED and a new Spirulina tank.

26/07: Day 00

27/07: Day 01



29/07: Day 03

31/07: Day 05

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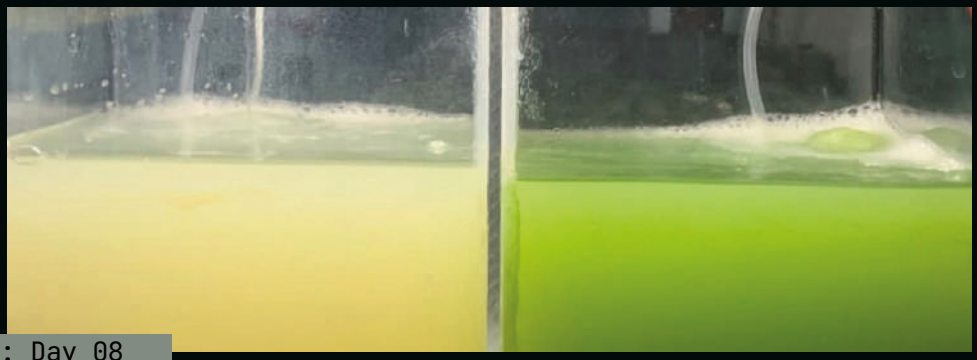
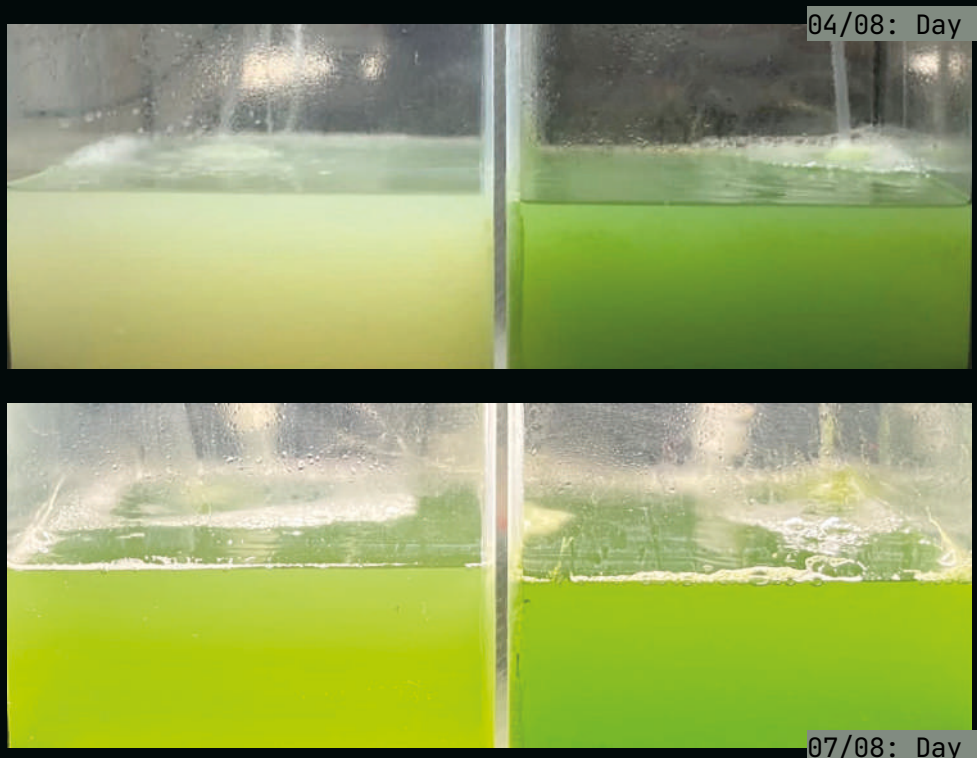


03/08: Day 08


04/08: Day 09
07/08: Day 12

BIOMASS HARVESTING

Exactly four weeks after the beginning of the culture, the biomass is harvested, as good amounts of sediment could be seen inside the thecae during mixing. It was therefore decided to use a 5µm filter, which is excellent for filtering both Chlorella and Spirulina biomass. For the first collection, only 500ml of culture is filtered: the filter is placed on a funnel and several cycles are carried out until no more sediment can be seen inside the liquid. The biomass remaining on the filter is collected with a teaspoon and placed inside a small plastic container, which is then stored in the refrigerator. The filtered liquid is also stored, which could be reinserted into the aquarium but in this case is replaced by new nutrients to encourage new biomass formation.

MICROLAGAE	LIQUID (mL)	WET BIOMASS (g)	DRY BIOMASS (g)	PERCENTAGE (%)
SPIRULINA	500	14.3	0.20	1.4
CHLORELLA	500	12.6	0.15	1.2

Table 2: First biomass collection data.

The process resulted in about 12.6g of wet biomass for Chlorella and 14.3g for Spirulina. These samples were then oven-dried for one hour at a temperature of 80 °C, resulting in a dry biomass of 0.20g for Spirulina and 0.15g for Chlorella. The biomass is now ready to be consumed, while the filtered liquid is excellent for use as fertiliser.

After a further four weeks, the culture has taken on a distinct shade of dark green, so the biomass is harvested

again, this time filtering 1.5L per tank. The process yields 31.6g of wet biomass for Chlorella and 62.3g for Spirulina. In this case, it is decided to sun-dry the harvest in order to avoid perishing of the material: Chlorella takes about 6 hours to dry out, while Spirulina takes 8 hours. Thus, 1.38g of dry biomass for Chlorella and 1.73g for Spirulina are harvested.

MICROALGAE	LIQUID (mL)	WET BIOMASS (g)	DRY BIOMASS (g)	PERCENTAGE (%)
SPIRULINA	1.500	62.3	1.73	2.7
CHLORELLA	1.500	31.6	1.38	4.3

Table 2: Second biomass collection data.

Fig. 18: Biomass on the filter after filtering the culture.

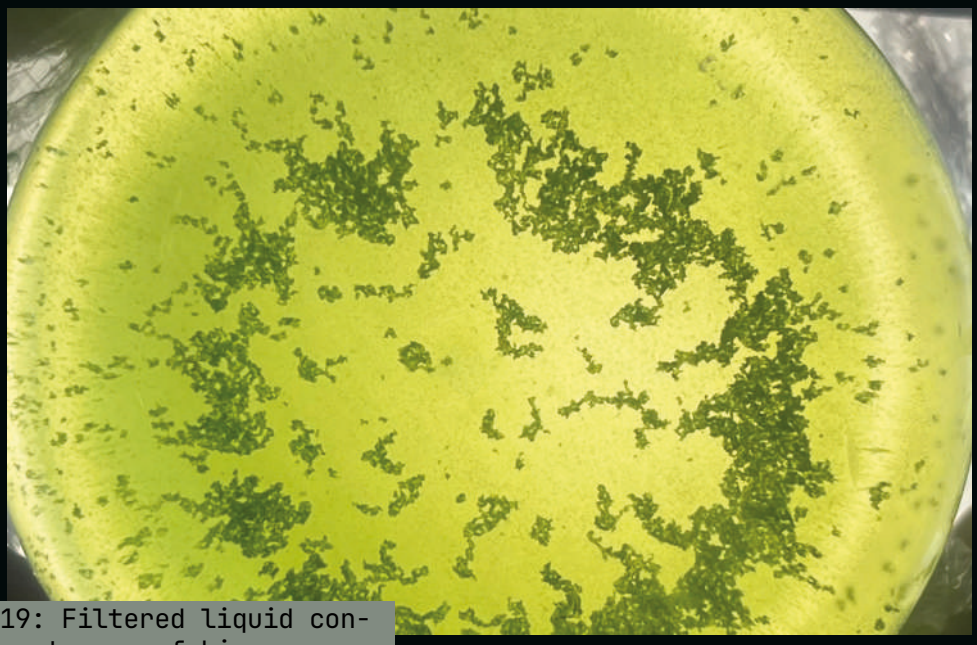


Fig. 19: Filtered liquid containing traces of biomass.

Fig. 20: Biomass removed from the filter using a spoon.

Fig. 21: The release of oxygen from sun-dried biomass.

EXPERIMENT

At this point, it is decided to conduct an experiment to assess the effectiveness of microalgae in absorbing carbon dioxide. The aim of the test is to show that, in an environment with a high CO2 concentration, the activity of microalgae can contribute significantly to reducing the CO2 level.

An airtight structure is therefore designed inside which the photobioreactor is placed. The theory is that by placing a lit candle inside to generate a high level of CO2, the activity of the microalgae will help to gradually reduce it. Since there is no gas exchange between the inside of the structure and the outside environment, if the CO2 level decreases, it is because the microalgae are consuming it to produce oxygen. Two MHZ19B infrared CO2 sensors are thus positioned at two different heights to ensure greater accuracy: sensor 1, positioned higher, detects data with a higher value as the gas tends to rise, while sensor 2 is positioned on the floor inside the structure.

The values of both sensors are then measured from the peak of 5000ppm (the maximum detectable by the sensors), reached when the combustion of the candle has consumed all the air inside the structure. Data is recorded on the Arduino's serial monitor every hour for the next 25 hours.

Figure 22: Test summary screen.

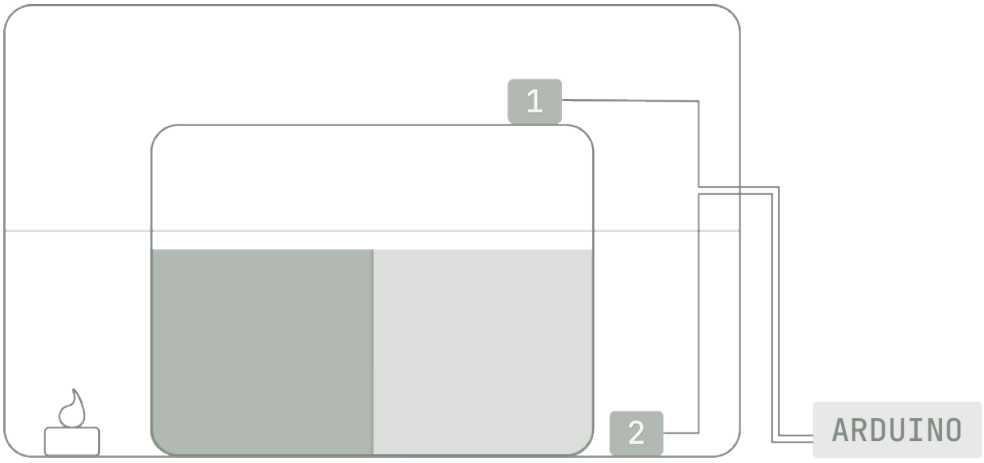


Figure 23: Setting up the photobioreactor in the box and reading out data.

MICROSCOPE ANALYSIS

At the end of the research phase, an analysis of the microalgae samples extracted from the photobioreactor followed using an optical microscope.

Each sample was carefully placed on a glass slide prepared for observation. Using magnifications ranging from X1 to X6.3, it was possible to identify the multi-cellular structures of Spirulina, observe the biomass formations and analyse the process by which oxygen bubbles are generated.

Figura 24: La postazione in FabLab Pesaro per gli scatti al microscopio.

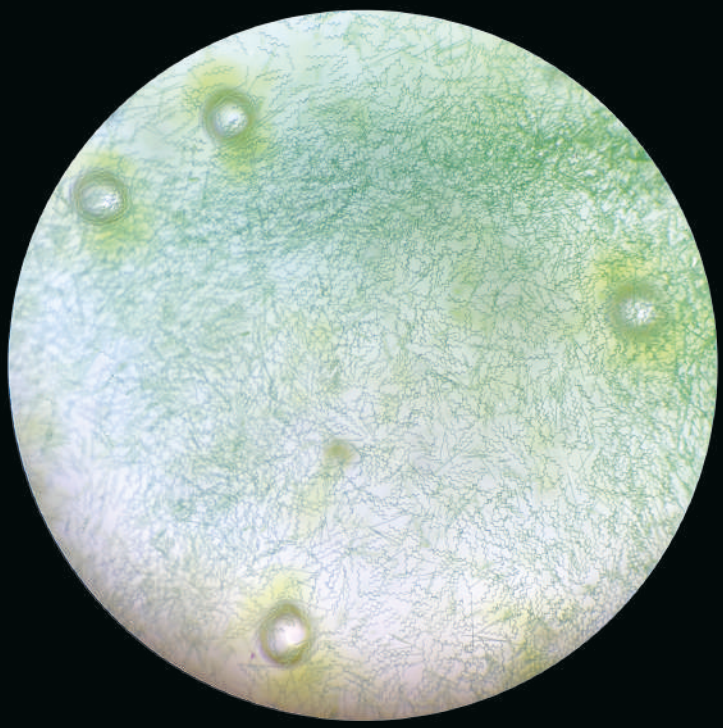
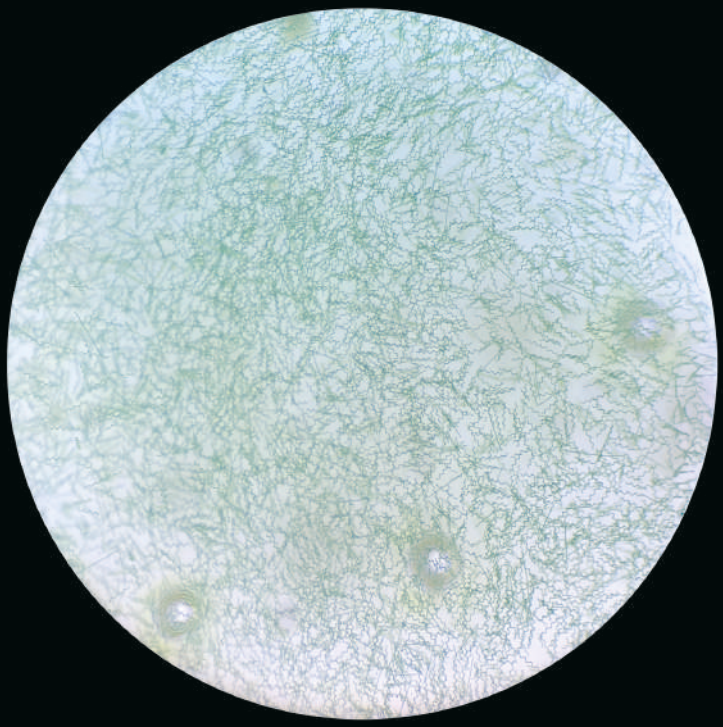
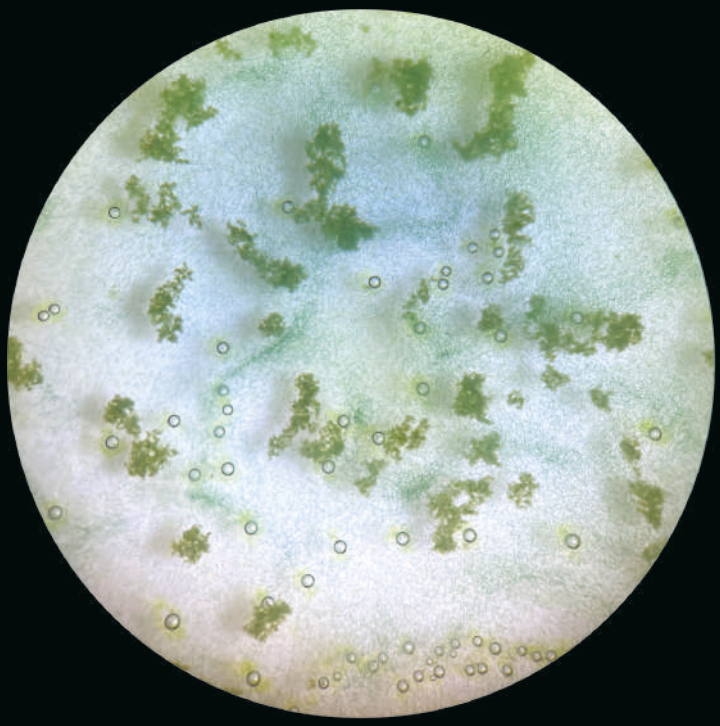
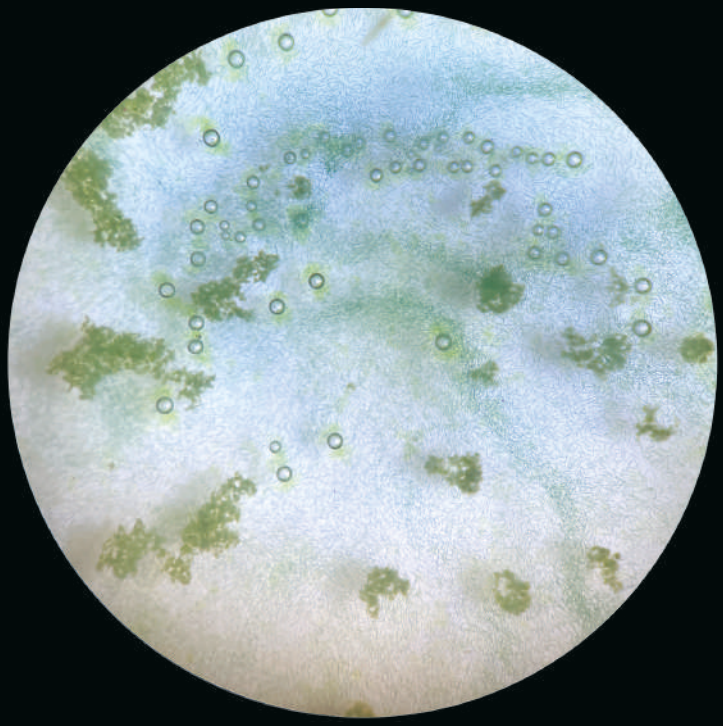


Fig. 25-28: Arthrospira Platensis (Spirulina).







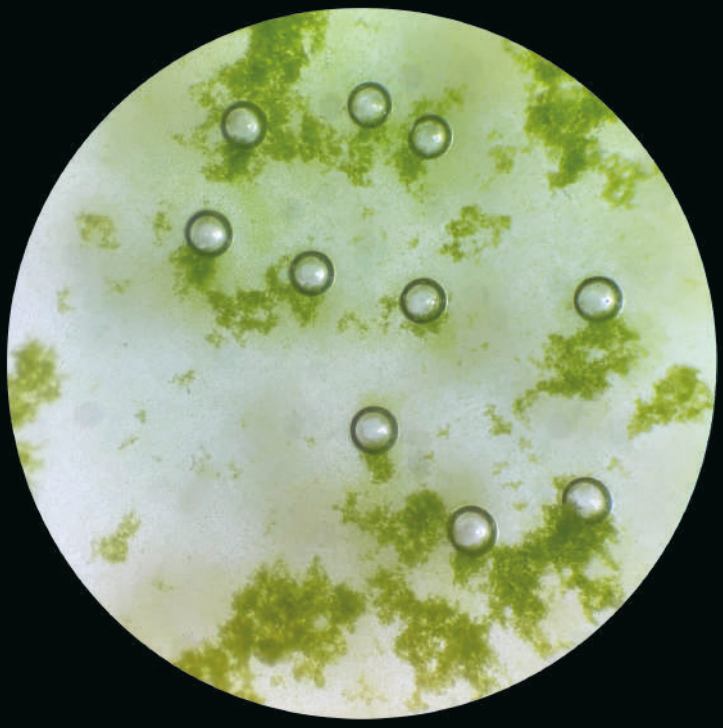
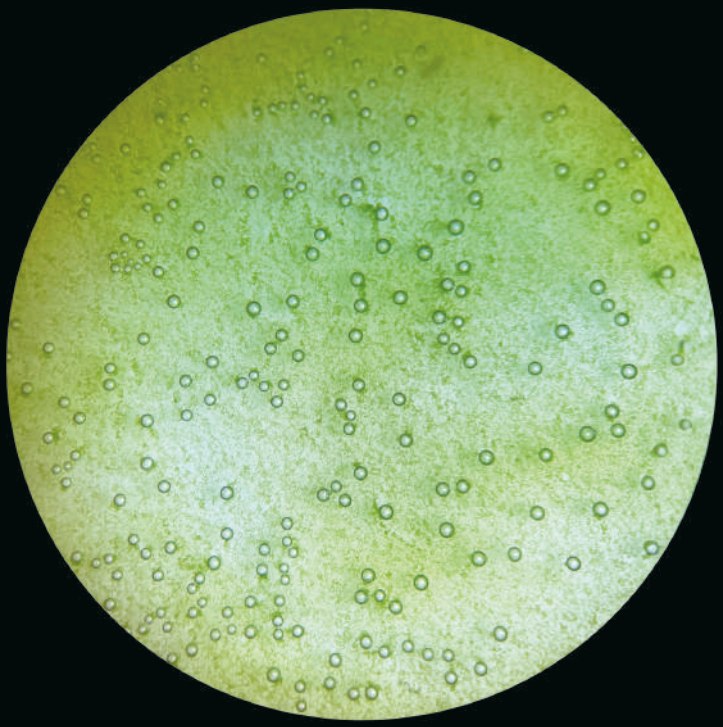
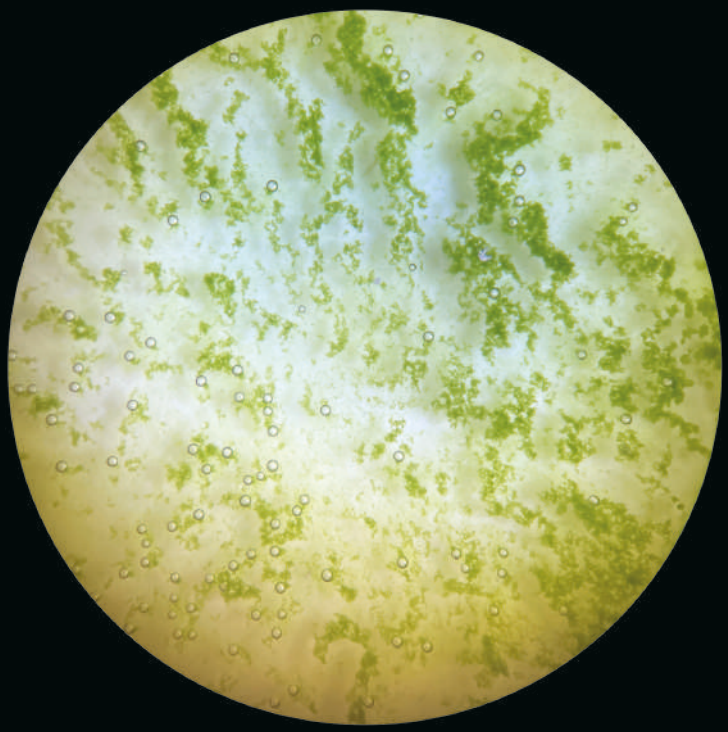
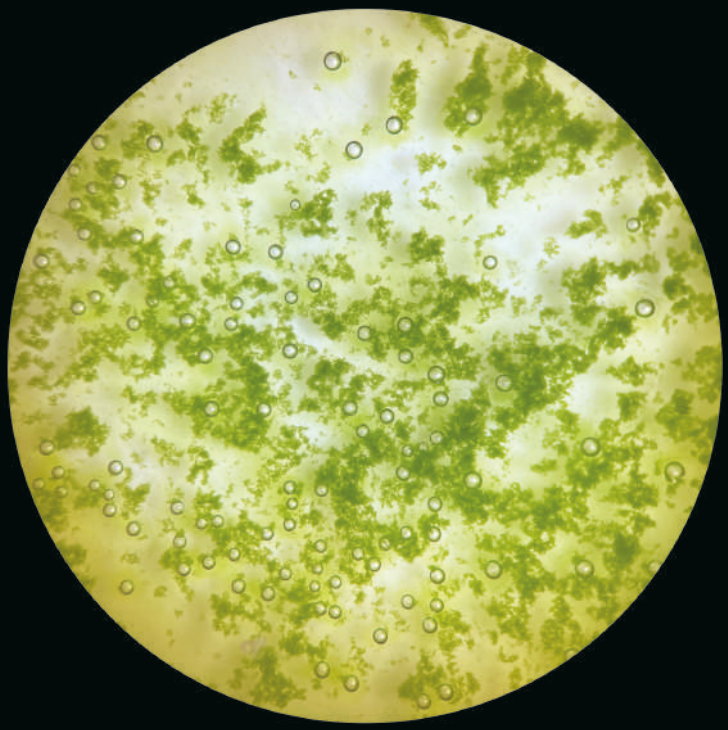


Fig. 29-32: Chlorella Vulgaris.







03.4 RESULTS AND DISCUSSION

13:35 Sensor 1 CO2: 5000 ppm
13:35 Sensor 2 CO2: 4614 ppm

14:35 Sensor 1 CO2: 4872 ppm
14:35 Sensor 2 CO2: 4420 ppm

15:35 Sensor 1 CO2: 4592 ppm
15:35 Sensor 2 CO2: 4192 ppm

16:35 Sensor 1 CO2: 4526 ppm
16:35 Sensor 2 CO2: 4006 ppm

17:35 Sensor 1 CO2: 4250 ppm
17:35 Sensor 2 CO2: 3904 ppm

18:35 Sensor 1 CO2: 4156 ppm
18:35 Sensor 2 CO2: 3763 ppm

19:35 Sensor 1 CO2: 3952 ppm
19:35 Sensor 2 CO2: 3587 ppm

20:35 Sensor 1 CO2: 3824 ppm
20:35 Sensor 2 CO2: 3479 ppm

21:35 Sensor 1 CO2: 3695 ppm
21:35 Sensor 2 CO2: 3339 ppm

22:35 Sensor 1 CO2: 3587 ppm
22:35 Sensor 2 CO2: 3222 ppm

23:35 Sensor 1 CO2: 3452 ppm
23:35 Sensor 2 CO2: 3089 ppm

00:35 Sensor 1 CO2: 3290 ppm
00:35 Sensor 2 CO2: 2996 ppm

01:35 Sensor 1 CO2: 3200 ppm
01:35 Sensor 2 CO2: 2926 ppm

02:35 Sensor 1 CO2: 3139 ppm
02:35 Sensor 2 CO2: 2837 ppm

03:35 Sensor 1 CO2: 2982 ppm
03:35 Sensor 2 CO2: 2751 ppm

04:35 Sensor 1 CO2: 2969 ppm
04:35 Sensor 2 CO2: 2646 ppm

05:35 Sensor 1 CO2: 2870 ppm
05:35 Sensor 2 CO2: 2568 ppm

06:35 Sensor 1 CO2: 2760 ppm
06:35 Sensor 2 CO2: 2491 ppm

07:35 Sensor 1 CO2: 2661 ppm
07:35 Sensor 2 CO2: 2410 ppm

08:35 Sensor 1 CO2: 2571 ppm
08:35 Sensor 2 CO2: 2295 ppm

09:35 Sensor 1 CO2: 2534 ppm
09:35 Sensor 2 CO2: 2276 ppm

10:35 Sensor 1 CO2: 2552 ppm
10:35 Sensor 2 CO2: 2205 ppm

11:35 Sensor 1 CO2: 2431 ppm
11:35 Sensor 2 CO2: 2130 ppm

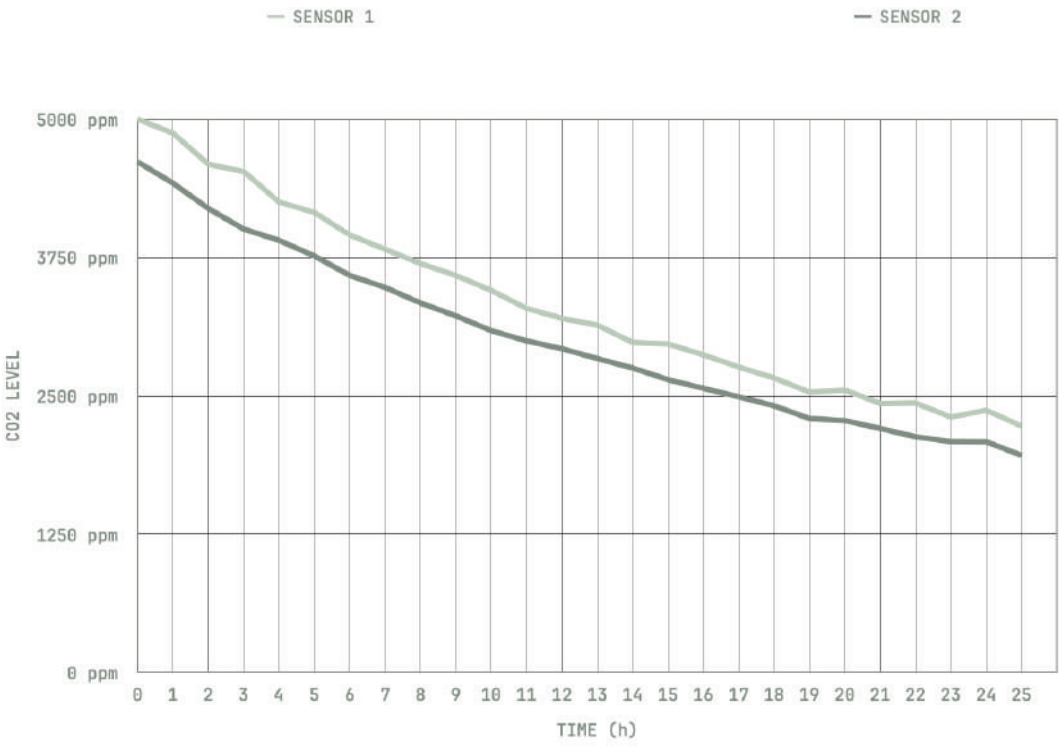
12:35 Sensor 1 CO2: 2435 ppm
12:35 Sensor 2 CO2: 2087 ppm

13:35 Sensor 1 CO2: 2308 ppm
13:35 Sensor 2 CO2: 2085 ppm

14:35 Sensor 1 CO2: 2370 ppm
14:35 Sensor 2 CO2: 2058 ppm

15:35 Sensor 1 CO2: 2226 ppm
15:35 Sensor 2 CO2: 1961 ppm

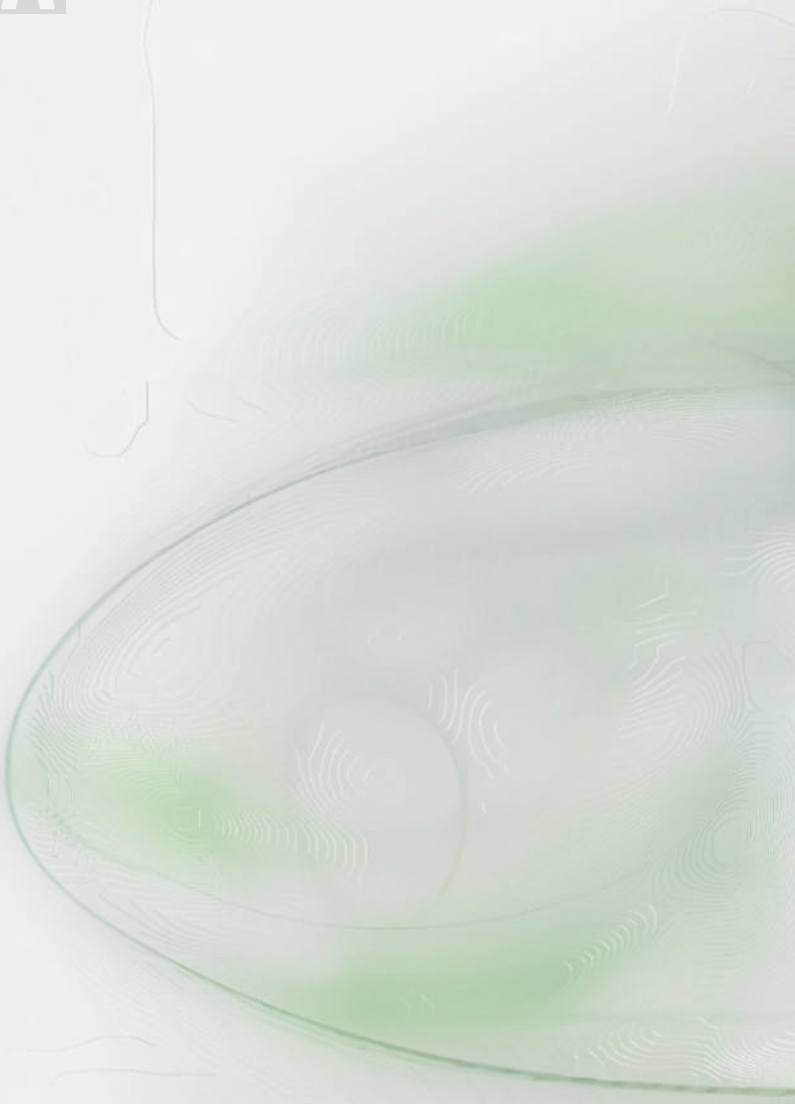
Figure 33: Trend graph for both CO2 sensors values over 25 hours.

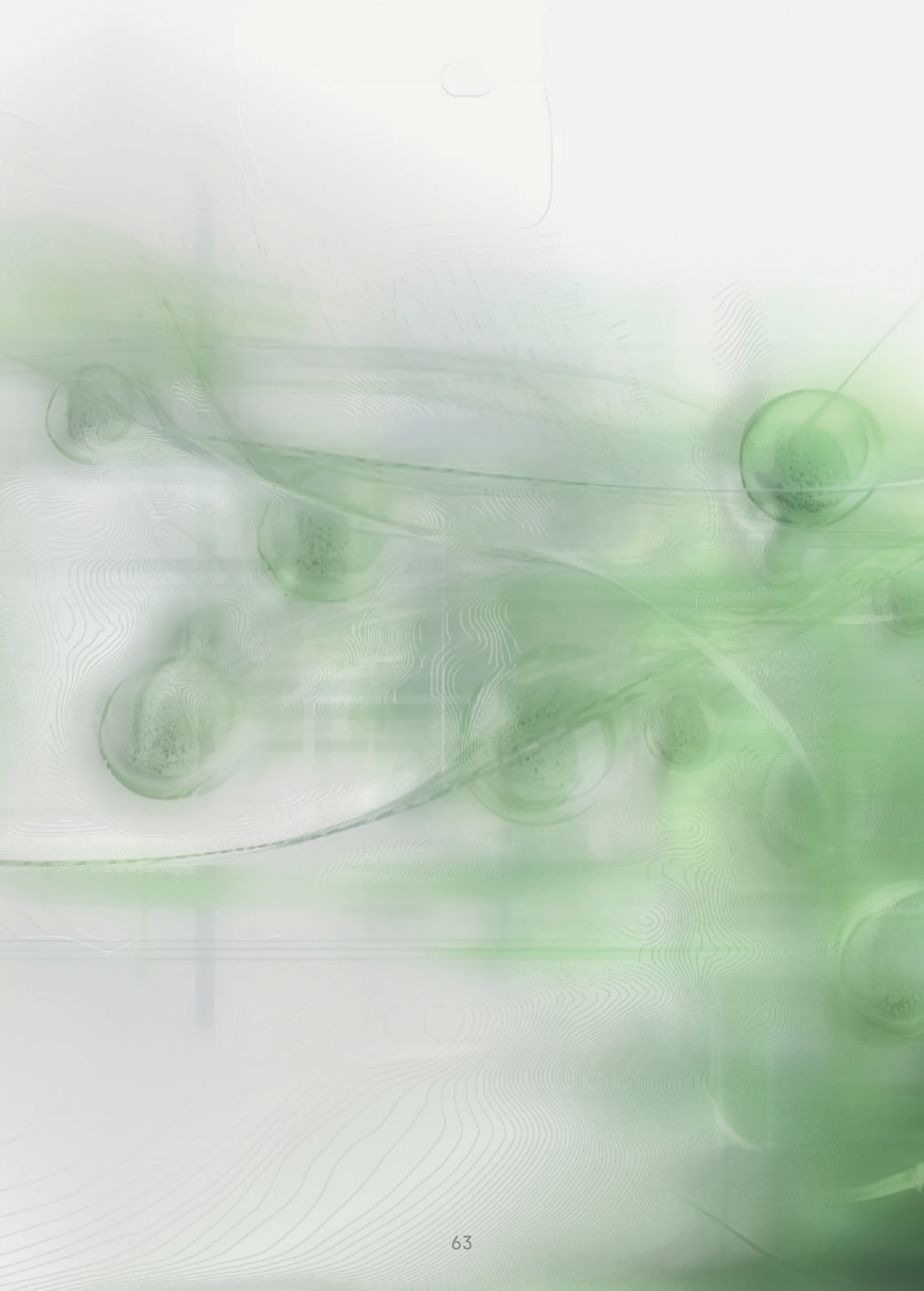


Analysis of the data obtained and observation of the relevant graph shows that in just 24 hours, the CO2 concentration fell from 5,000ppm to 2,226ppm, a reduction of 55.48%, confirming the effectiveness of the photosynthesis carried out by the microalgae in purifying the indoor air.

Although the experiment should be replicated to ensure greater validity of the results, the huge contribution made by microalgae in producing oxygen remains a tangible demonstration of their importance to life in our biosphere.

04. SPIRA





04.1 CONCEPT

SPIRA's goal is to take microalgae cultivation beyond the academic and research sphere, by bringing the benefits and knowledge associated with this practice into the public domain. Although microalgae have demonstrated considerable potential, their applications on a personal scale are still insufficiently explored, remaining mostly confined to the industrial context.

SPIRA aims to reverse this perspective, highlighting how feasible and advantageous it is to adopt microalgae cultivation systems on a small, accessible and easily controlled scale. The ambition is to exploit the biodesign methodology to bridge the gap between specialised research and general knowledge, promoting inter-species collaboration with microalgae as a viable and concrete tool to address the challenges of the climate crisis. A broader understanding and dissemination in this field could also stimulate further research into biofuels derived from microalgae biomass with a bottom-up strategy, in order to address the urgent need to investigate alternative energy sources.

Besides being an opportunity to learn more about or directly experience microalgae cultivation, SPIRA also wants to highlight the multiple benefits of
this practice, such as having a biological air purifier and exploiting the unique properties of biomass.

To achieve this, SPIRA is structured on three main axes:

- TOOLKIT: This kit represents a complete benchmark for those wishing to cultivate microalgae. At present, there are no similar tools available to make this practice easier for those unfamiliar with the field. The toolkit is designed to be intuitive and affordable, guiding the user step by step through the cultivation of microalgae.

- DIY: Detailed instructions are provided to construct a simple microalgae photobioreactor independently, adaptable to varying degrees of expertise. This reflects the independent design ethos inherent in the field, making the practice reachable to anyone.

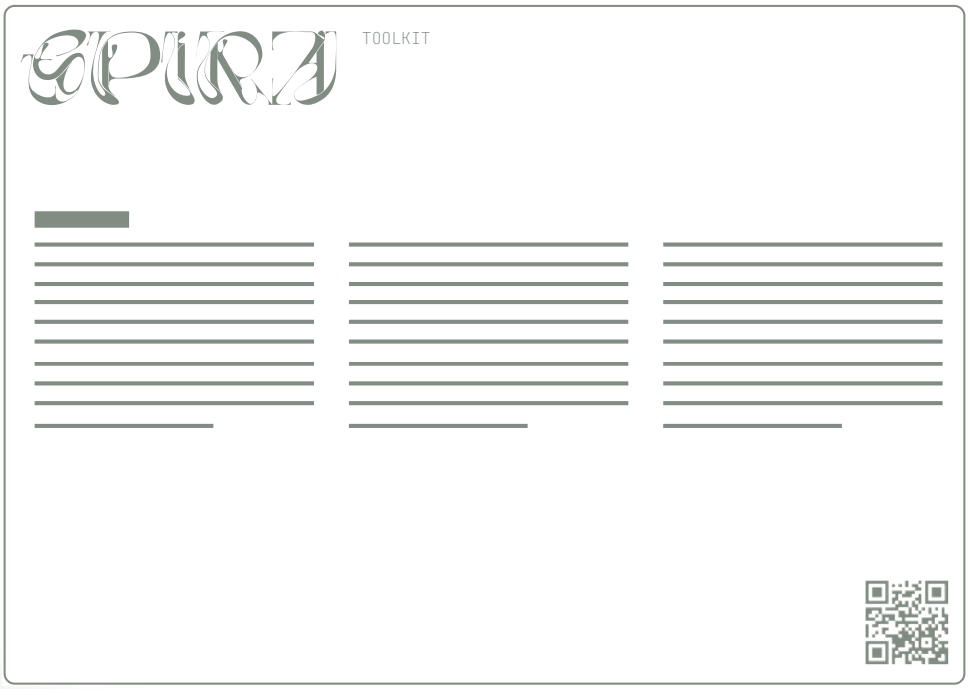
- WEBSITE: A dedicated online platform where research results and the genesis of the project are shared. It is a space designed to offer clear guidelines and provide a point of orientation in a field that, until now, has remained outside the general knowledge.

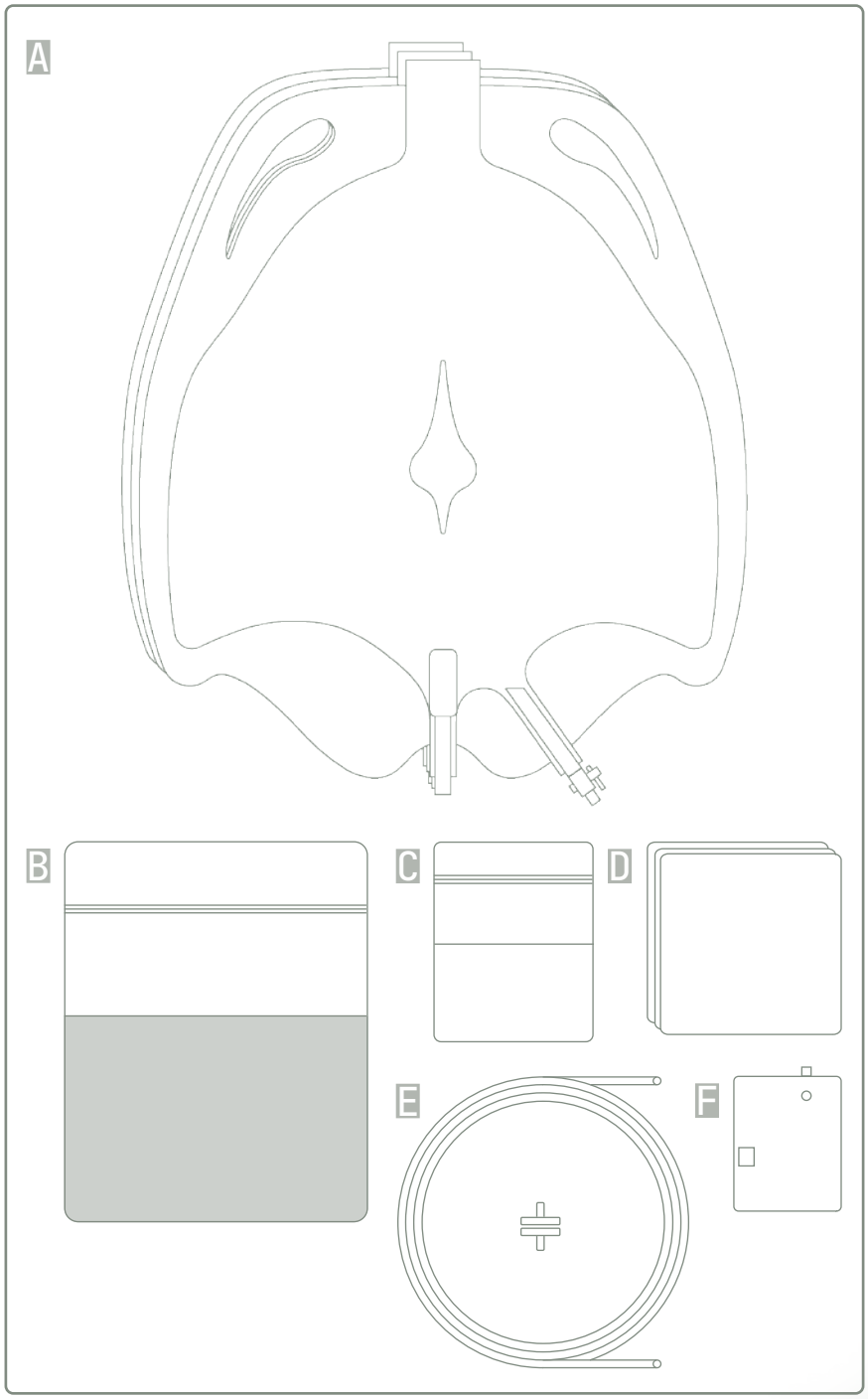
04.2 TOOLKIT

The following items are included in the toolkit:

[X] GUIDE
[A] PHOTOBIOREACTORS (X3)
[B] MICROALGAE (200ml)
[C] NUTRIENTS (10g)
[D] 5µm FILTERS (X3)
[E] AERATION
[F] IoT MODULE

X




A
B
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04. SPIRA - TOOLKIT

X. GUIDE

A practical guide is included in the toolkit to assist the user in its utilisation. It lists the components supplied with their characteristics, as well as instructions for optimum procedure and maintenance of the cultivation. There is also a QR-Code on the sheet to link to the SPIRA website and access other useful information for one's own cultivation.

A. PHOTOBIOREACTORS (X3)

Three structures designed to accommodate 1L of microalgae each are provided in the toolkit. The design differs from other commercially available photobioreactors in one key strategy: the use of flexible materials.
Not only is the production of a rigid container a costly operation requiring large amounts of materials and manufacturing, but it could also be replaced more sustainably and economically by a simple plastic bottle. Adopting this kind of approach also means increasing the CO2 emissions required for the production of the final product, reducing the chances of this being offset by the activity of the microalgae and its longevity.For this reason, an elastic structure was chosen in the design of the photobioreactor.

This is accomplished by the technique of laser welding, in which plastic sheets are sealed to form closed chambers. Laser welding allows the construction of a structure that meets the requirements of transparency, lightness, low material consumption and transportability, as well as being more practical for modular use and leaving ample versatility for design.

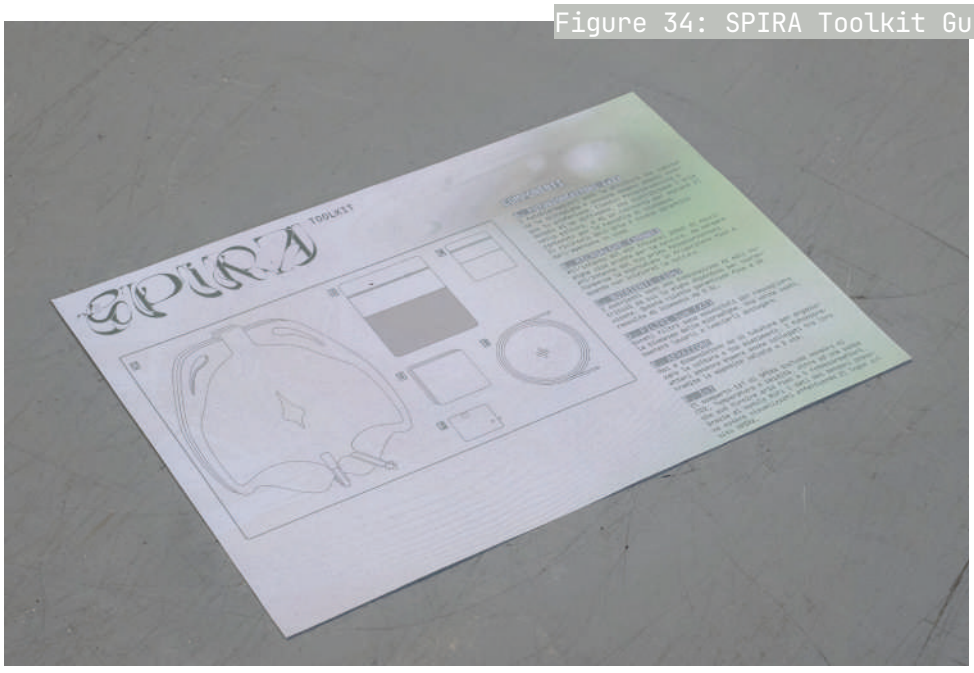


Figure 34: SPIRA Toolkit Guide.

Figure 35: The three photobioreactors.

04. SPIRA - TOOLKIT

The selected material are waste sheeets of LDPE (low density polyethylene) intended for packaging with a thickness of approximately 10µm, recovered through an upcycling process. LDPE is ideal for the purpose because its tear-proof and transparent properties make it a resilient and effective habitat for microalgae.

Each photobioreactor is equipped with an internal diffuser that nebulises the pumped air, so that the carbon dioxide is absorbed by the microalgae more effectively and uniformly. In addition, there is a tap at the bottom of the structure, which is used to collect the biomass that accumulates at the bottom. Upon collection, the tap can be opened to allow the liquid to be filtered and, subsequently, reinserted through the opening at the top. This same opening allows both the supply of nutrients and the recirculation of air between the photobioreactor and the external environment, providing some protection from impurities.

The photobioreactor is designed to be hung, a feature that makes it usable in a variety of contexts: it can be attached to a window, favoured by natural light, or to a wall or ceiling.

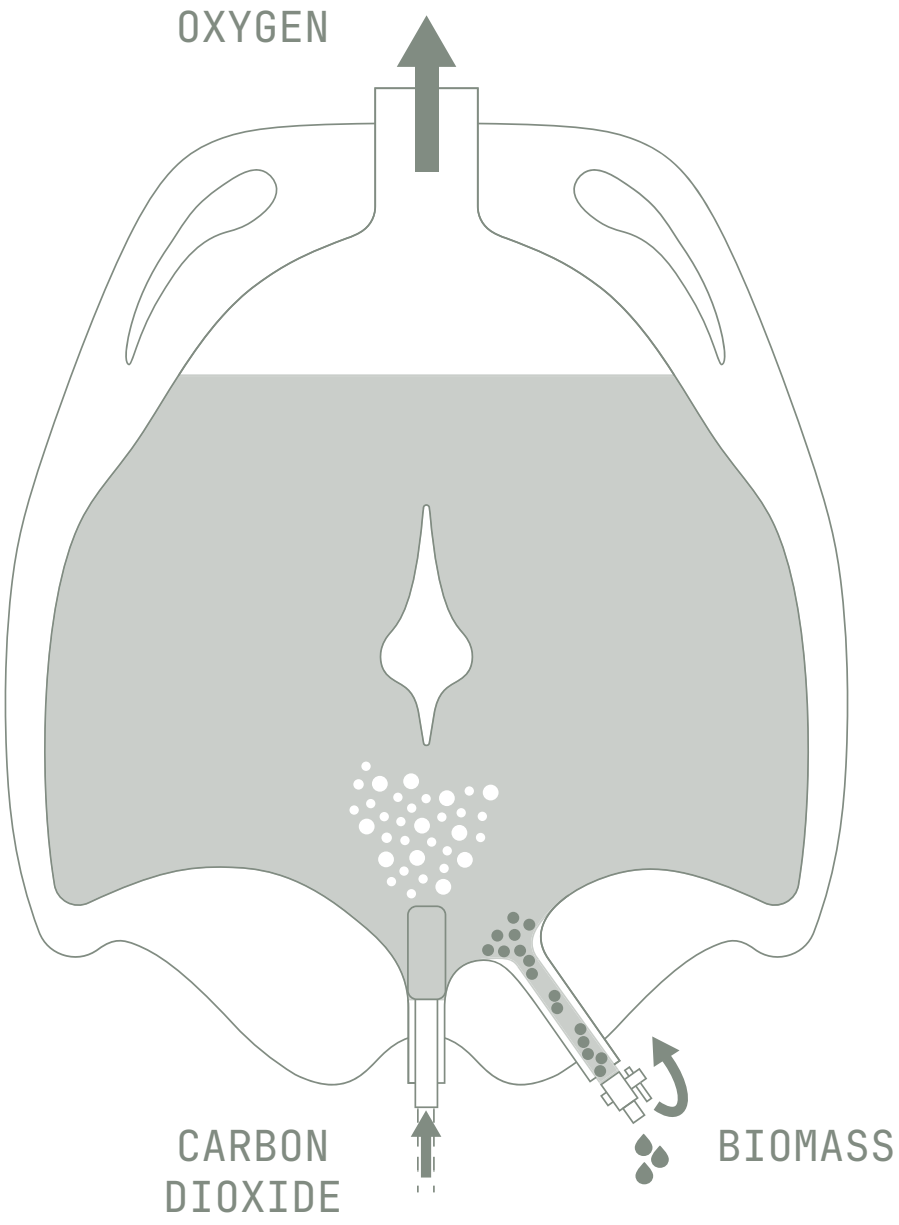


Figure 36: Illustrative diagram of photobioreactor operation.

B. MICROALGAE (200mL)

The SPIRA toolkit focuses on Spirulina (Arthospira Platensis), as the best-known and most widespread microalgae species on the market.

However, this does not limit the applicability of the toolkit exclusively to this specie, since it has been designed to be versatile and adaptable to different types of microalgae. The focus has been on flexibility of choice by assuming different versions of the toolkit, each suitable for the selected species, which will be supplied with the appropriate nutrients.

C. NUTRIENTS (10g)

Inside the set are 10g of powdered nutrient salts essential for promoting microalgae growth. The selected formula is Bold's Basal Medium (BBM) at a concentration reduced by 50% compared to the standard. This medium, adaptable to a wide range of algae, promotes exponential growth of microorganisms when using half its usual concentration. This not only optimises costs but also maximises the effectiveness of the nutrients included in the kit; for example, with the 10g supplied, one can accomplish 20 harvests of half a litre each.

Figure 37: Sealed bag with 200ml of live microalgae.

Figure 38: Bag with 10g of nutrients.

D. FILTERS (X3)

To collect the biomass deposited at the bottom of the photo-bioreactor, it is essential to use 5µm filters. Three of these 12x12cm filters are included iand can be washed and reused after each use. The softer side is the one on which to pour the liquid.

E. AERATION SYSTEM

Also supplied are 4mm pipes and the 3-way valves required to make the connections between the photobioreactors and the pump. These components are essential to guarantee a continuous flow of carbon dioxide, ensuring the needs of microalgae. Thanks to these connections, it is also possible to expand one's system from one to several tanks, while still maintaining a controlled micro-environment.

Figure 39: Three 5µm filters.

Figure 40: The 4mm pipes with their 3-way valves.

F. IoT MODULE

The electronic components are located in a compact case that contains both the pump, which draws air from the environment into the photobioreactors, and the IoT module. SPIRA's photobioreactor is equipped with a series of sensors designed to closely monitor the conditions of the culture:

- CO2 SENSOR: This is used to assess the air quality within the designed area. An estimate of the concentration of carbon dioxide in the environment is essential to prevent an excess that could cause fatigue and other negative consequences. This sensor can suggest to the user to aerate the environment, either by enlarging their culture with an additional module or by opening a door or window.
- TEMPERATURE AND HUMIDITY SENSOR: This sensor is essential to determine whether the habitat conditions are ideal for the microalgae and, if necessary, to intervene by modifying its position to regulate the temperature and humidity.

The data collected by these sensors are transmitted, via a Wi-Fi module, to the user's personal account on the SPIRA website, where it can be viewed in real time.
The entire compartment can be powered with negligible energy consumption thanks to a common USB-C cable.

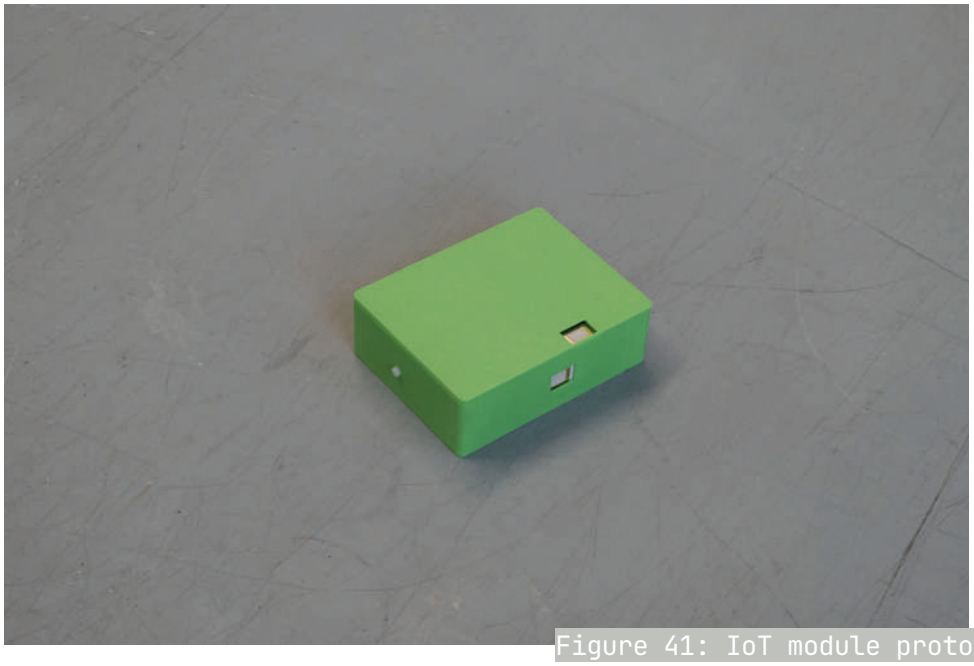


Figure 41: IoT module prototype.

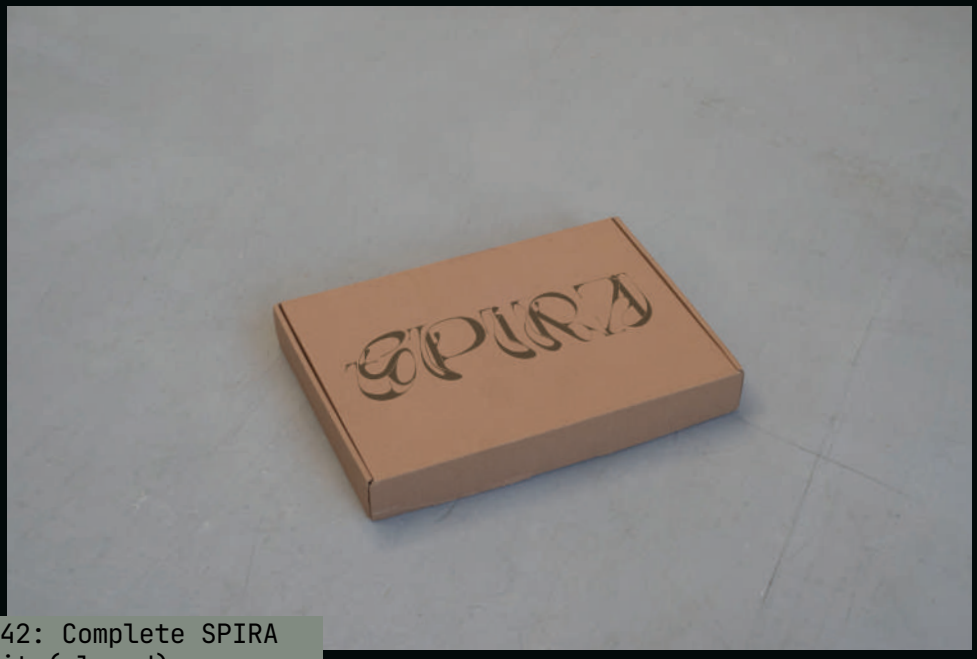


Fig. 42: Complete SPIRA toolkit (closed).

Fig. 42: Complete SPIRA toolkit (open).

Fig. 44-46: Toolkit in action with microalgae.

04.3 DIY

SPIRA is extended with DIY versions designed to be self-built according to different skill levels.

This is to support the idea of open-access design that breaks the barriers of gatekeeping in favour of shared knowledge. The following models are laid out as one of the possible examples for undertaking microalgae cultivation independently, and are not intended to be the only possible solution. Anyone is free to modify, improve and redistribute these versions to better suit their own needs.

Instructions for making the two versions of the kit are given below.

Figure 47: The assembled DIY version of the toolkit.

04. SPIRA - DIY

DIY - BASIC

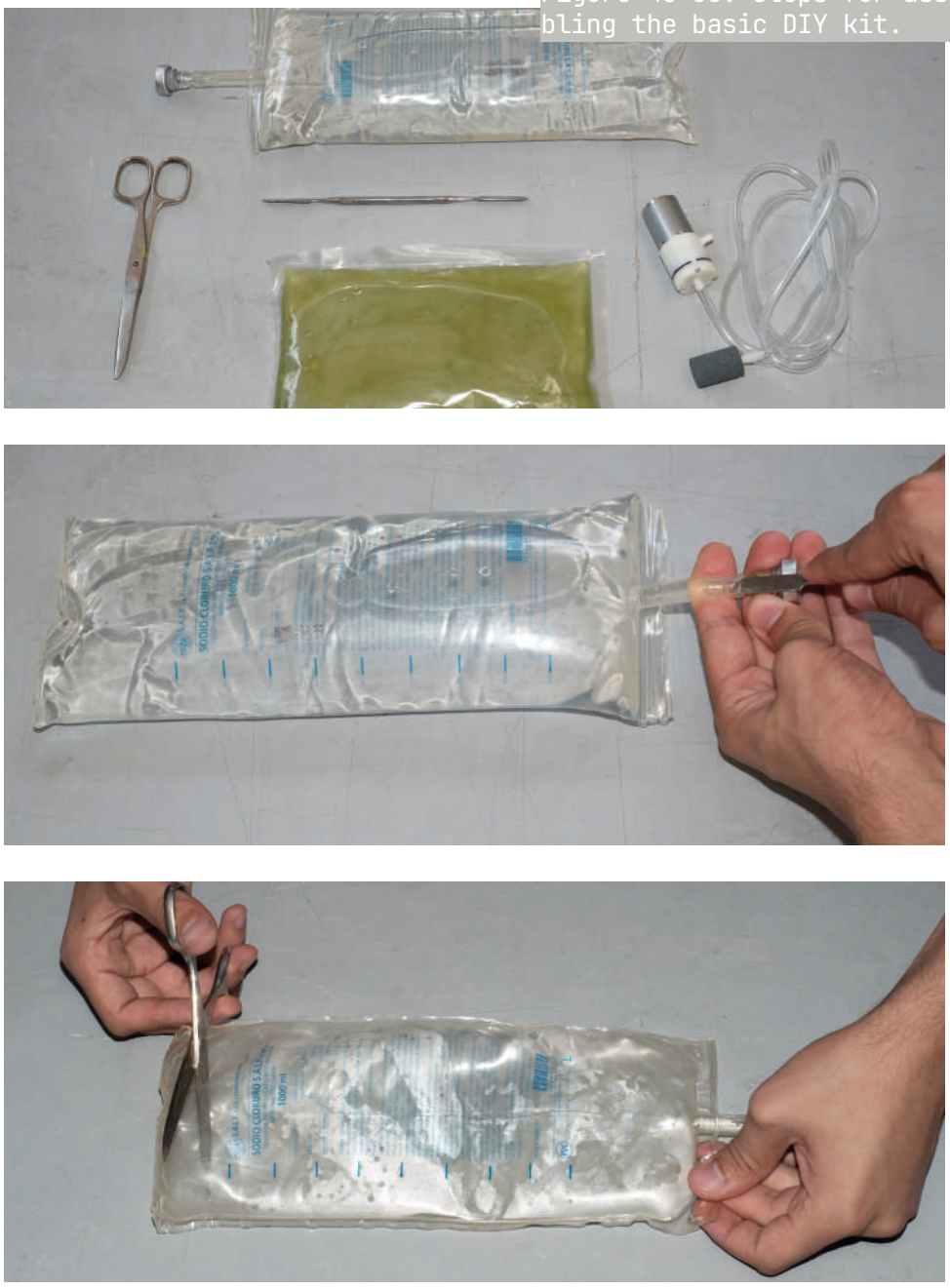
MATERIALS

MATERIALS	QUANTITY	PRICE
MICROALGAE & NUTRIENTS	200 ml	~€20
IV BAG (1L)	1	€6
USB AQARIUM PUMP	1	€15
5µm FILTER	1	€12
		TOT: €53

INSTRUCTIONS

1. Remove the cap of the bag from the side with the help of a screwdriver
2. Drain the liquid inside and close the bag.
3. Cut a hole of about 1 cm at the top of the IV bag.
4. Insert the tube with the diffuser inside the bag.
5. Pour the nutrients inside using a syringe or funnel.
6. Pour in the microalgae.

Figure 48-50: Steps for assembling the basic DIY kit.



DIY - ADVANCED

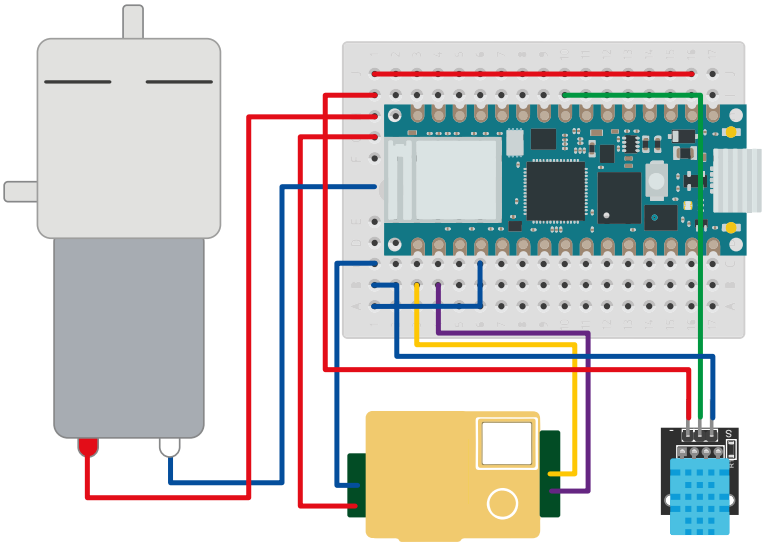
MATERIALS

MATERILAS	QUANTITY	PRICE
MICROALGAE & NUTRIENTS	200 ml	~€20
IV BAGS	1-5	€6
6V PUMP	1	€2
AIRSTONES	1-5	€2
TUBES & VALVES	4m	€5
ARDUINO NANO RP2040	1	€33
BREADBOARD + JUMPER	1	€8
CO2 SENSOR	1	~€20
TEMPERATURE SENSOR	1	€2
5µm FILTER	1	€12
		TOT: €110

INSTRUCTIONS

1. Carry out the first 4 steps of the BASIC version
2. Make the electrical connections according to the diagram.
3. Open the Arduino IDE app on your PC and open a new Sketch on which to paste the code shared on the SPIRA website.
4. Connect the Arduino to your PC and upload the code via the Arduino IoT platform.
5. The .STL file for 3D printing the case to house the electronic components is also provided.

Figure 51: Wiring diagram for the advanced DIY kit.



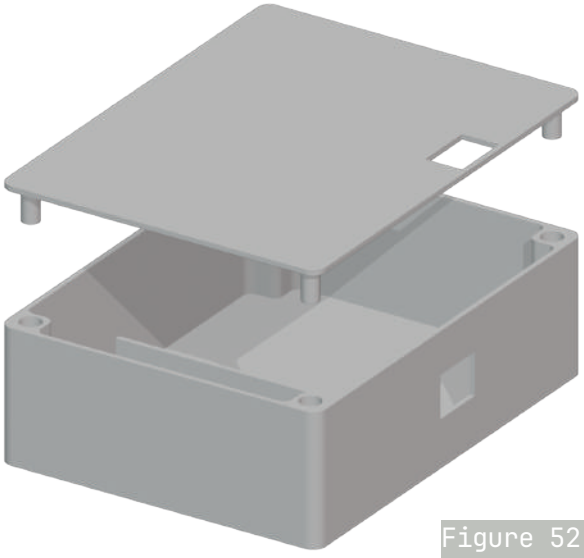


Figure 52: The 3D model for printing the case.

Fig. 53-54: The DIY kit in action with microalgae.

04.3 WEBSITE

The SPIRA website presents itself as an integrated platform focused on the universe of microalgae and their cultivation. In addition to managing interactions related to the Toolkit, it offers users an opportunity to both learn and share on the subject.

The 'Research' section hosts a short summary highlighting salient information on microalgae and their role in relation to the climate crisis. This section also includes a forum, creating a space for users to share their experiences, resolve doubts and expand their knowledge. The 'DIY' section, on the other hand, provides the instructions needed to assemble the kits themselves.

Users have the option of ordering either the complete toolkit or specific extensions, such as additional sets of photobioreactors or supplies of microalgae and nutrients.
After logging in with their credentials, users can connect their toolkit to Wi-Fi and monitor their cultivation data in real time.

These sections, which together form the heart of the SPIRA platform, aim to build a vibrant and passionate community.

https://nicolobaldi.com/SPIRA

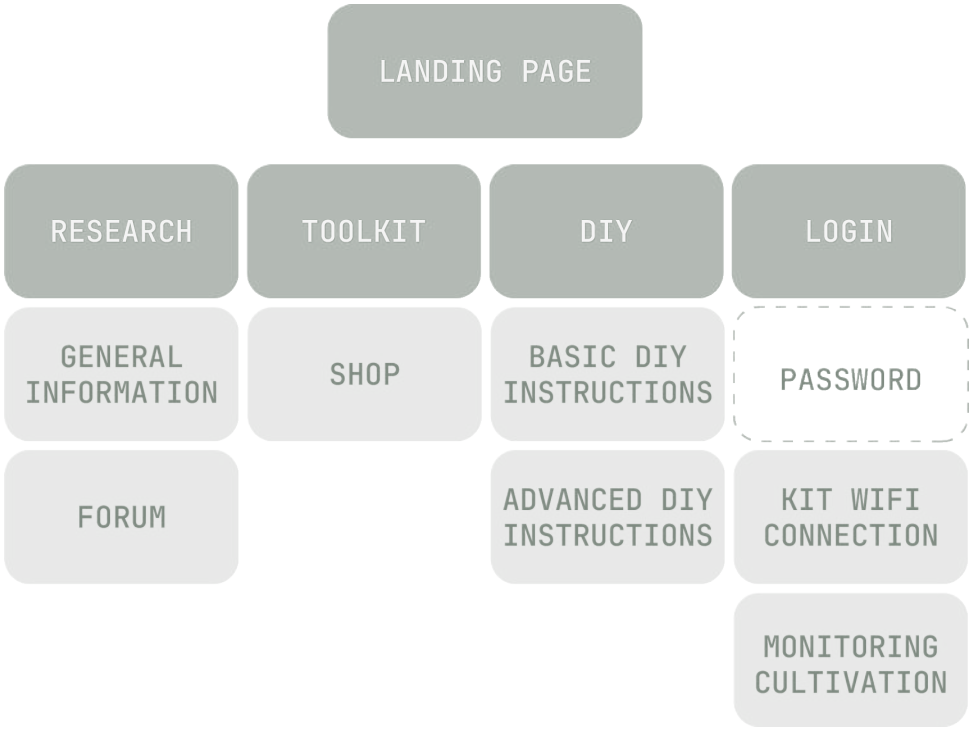
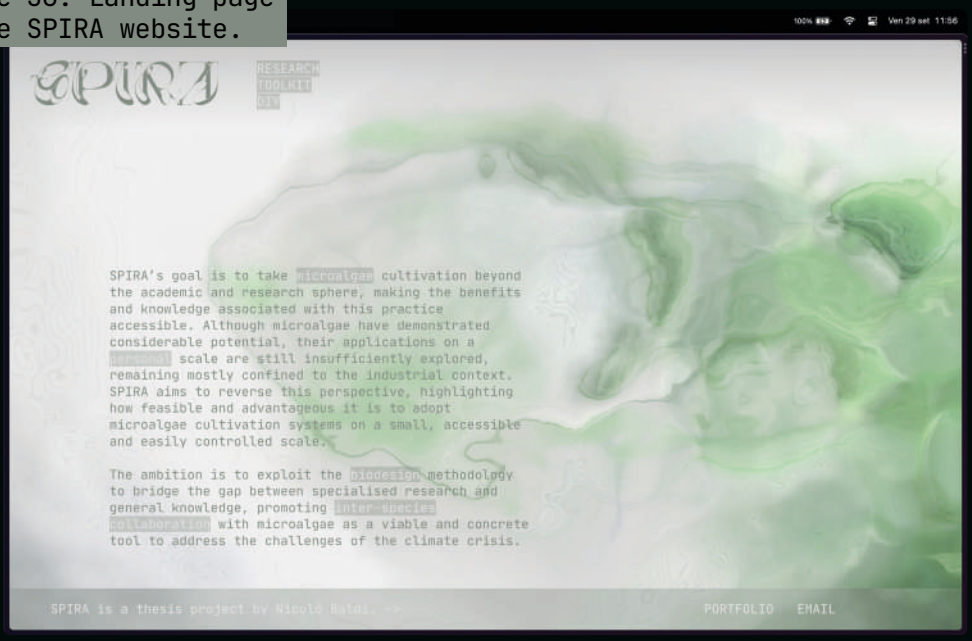


Figure 55: SPIRA website navigation tree.

Figure 56: Landing page of the SPIRA website.


SPIRA
RESEARCH
TOOLKIT
ABOUT
SPIRA's goal is to take microalgae cultivation beyond the academic and research sphere, making the benefits and knowledge associated with this practice accessible. Although microalgae have demonstrated considerable potential, their applications on a domestic scale are still insufficiently explored, remaining mostly confined to the industrial context. SPIRA aims to reverse this perspective, highlighting how feasible and advantageous it is to adopt microalgae cultivation systems on a small, accessible and easily controlled scale.
The ambition is to exploit the biodesign methodology to bridge the gap between specialised research and general knowledge, promoting inter-species collaboration with microalgae as a viable and concrete tool to address the challenges of the climate crisis.
SPIRA is a thesis project by Nicolò Botoli. ->
PORTFOLIO
EMAIL

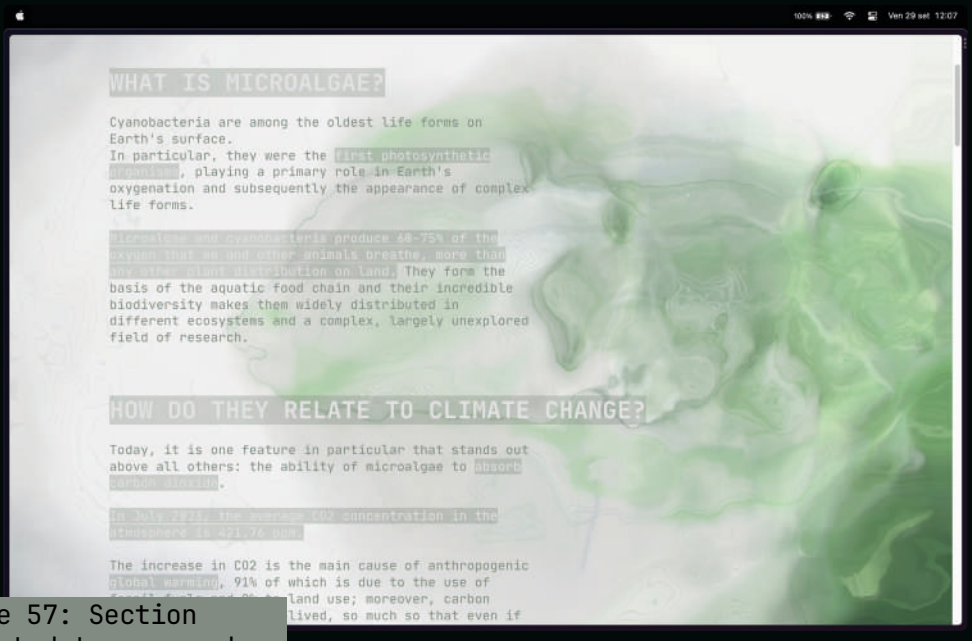

WHAT IS MICROALGAE?
Cyanobacteria are among the oldest life forms on Earth's surface.
In particular, they were the first photosynthetic organisms, playing a primary role in Earth's oxygenation and subsequently the appearance of complex life forms.
Microalgae and cyanobacteria produce 60-75% of the oxygen that we and other animals breathe, more than any other plant distribution on land. They form the basis of the aquatic food chain and their incredible biodiversity makes them widely distributed in different ecosystems and a complex, largely unexplored field of research.
HOW DO THEY RELATE TO CLIMATE CHANGE?
Today, it is one feature in particular that stands out above all others: the ability of microalgae to absorb carbon dioxide.
In July 2021, the average CO2 concentration in the atmosphere is 421.76 ppm.
The increase in CO2 is the main cause of anthropogenic global warming, 91% of which is due to the use of
land use; moreover, carbon
lived, so much so that even if

Figure 57: Section dedicated to research.

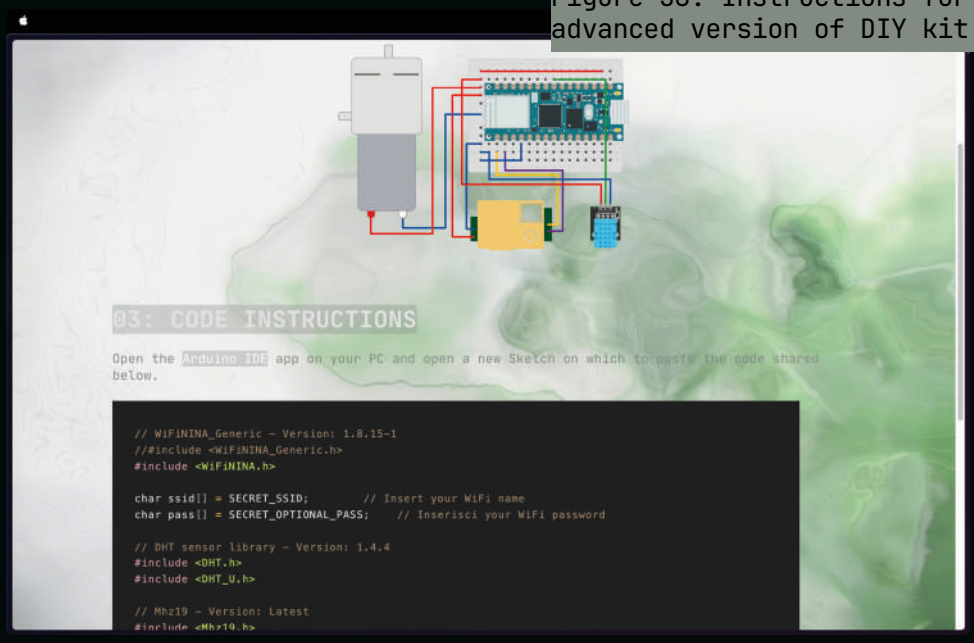


Figure 58: Instructions for the advanced version of DIY kit.

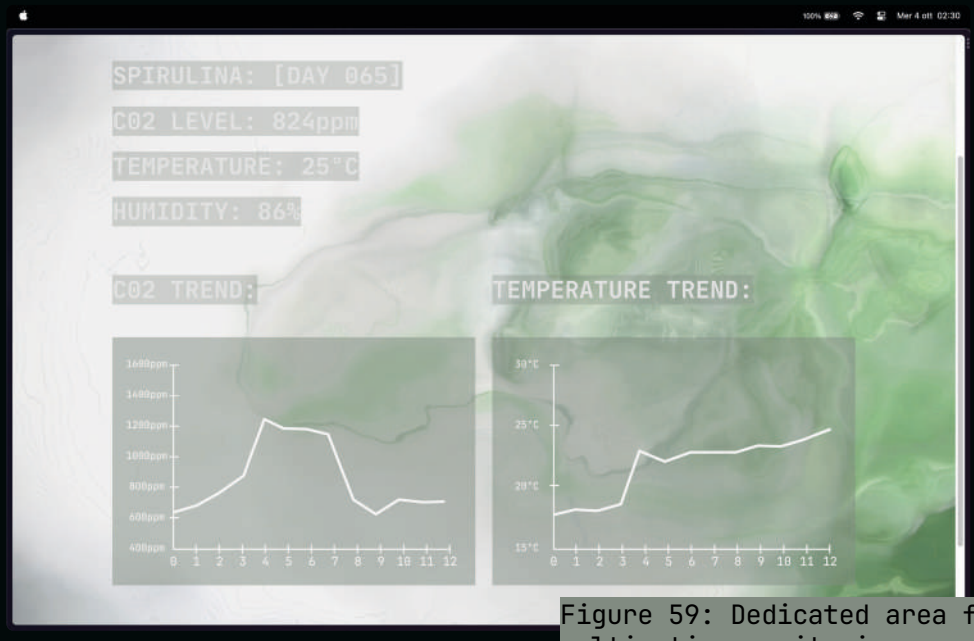


Figure 59: Dedicated area for cultivation monitoring.

04.4 PROTOTYPING

The prototyping process was carried out in cooperation with the FabLab Pesaro at Cosmob, under the supervision of head Christian Gabbani.

During this phase, the technique of laser welding was explored to create the structure of the photobioreactor. This technique was studied in the context of Soft Robotics, a field dedicated to robots built from inflatable and flexible materials. The main references on this technique come from guides on the Instructables platform and the work of Marisa Satsia, a multidisciplinary artist and researcher specialised in biological arts. [29]

Having had the opportunity to meet Marisa in personally during the "Biofabricated Soft Robots & Inflatables" workshop organised by Umanesimo Artificiale at FabLab Pesaro has certainly stimulated an interest in learning more about this technique. The opportunity to experiment directly with these prototyping tools has also greatly influenced the design of the photobioreactor. [30]

Figure 60: 'Biofabricated Soft Robots & Inflatables' with Marisa Satsia. FabLab Pesaro, July 2023, photo by Davide Marcianesi.

04. SPIRA - PROTOTYPING

MATERIALS

As in the references above, LDPE (low-density polyethylene) was chosen as the target material.
LDPE is particularly suitable for this process because, unlike other plastics such as PVC, it does not emit harmful gases during laser processing. Furthermore, the material was recovered from industrial waste in the packaging industry, making the operation a true example of upcycling. The studies were conducted from 3mx2m sheets with a thickness of 10µm.

PRELIMINAR RESEARCH

In order for the laser to perform a welding operation and not a cutting operation on the overlapping plastic sheets, it was necessary to reduce its power. However, even if the power was reduced to a minimum, the laser could still cut through the thin plastic layers. Therefore, the laser was positioned out of focus, increasing the distance between the light beam and the supporting surface.

In this way, the laser is less powerful and more distributed over the sheet, greatly increasing the chance of welding.It is important to emphasise that this technique is only effective if the plastic sheets are in close contact, and numerous tests were conducted during the research to favour this condition. Furthermore, the use of scrap sheets, which had suffered wear and tear and had creases or deformations, hindered some successes during the research.The designs of the photobioreactors were developed on AutoCAD, and the cutting instructions were provided via LaserSoft V7.02 software using a DXF format file.

Figure 61: Selected LDPE waste sheets.

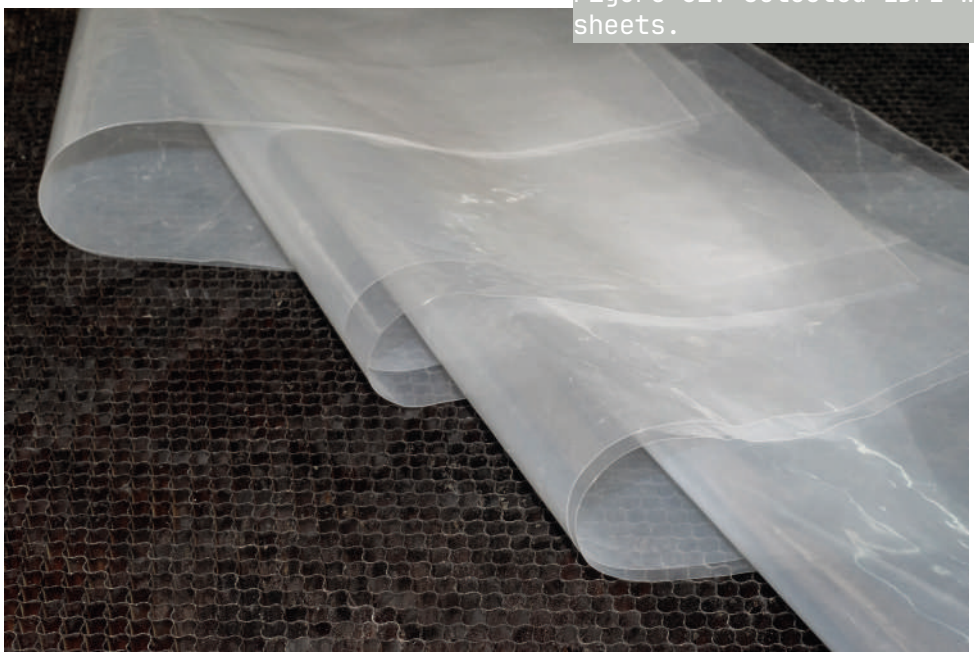


Figure 62: FabLab Pesaro laser cutting machine.

TESTS

The first phase of the research focused on the delicate balance between the machine's parameters, namely:

- OUT OF FOCUS (mm): the distance between the light beam and the surface.
- SPEED (mm/s): the speed at which the laser moves.
- POWER (%): the parameter to indicate the percentage of cutting force.
- POWER AT CORNERS (%): to indicate the power at the cutting corners.

Next, the focus shifted on how to achieve better adhesion between the plastic sheets during welding. Initially, the sheets were tensioned by securing them with adhesive tape, but this turned out to be insufficient. Therefore, the idea was to place a weight inside the welding area to encourage contact between the sheets in the desired area.

It was then continued by shrinking the inner geometry by 10mm and cutting a sheet of acrylic, and then securing it in the intended area with magnets. In order to get a preliminary idea of how best to position the acrylic, it was decided to make a very low-power guide to mark the boundary of the inner area. In order to further improve the effectiveness of the operation, it was decided to perform a second welding with an external offset of 4mm.The external cut of the photobioreactor was instead realised by repositioning the laser in focus, in order to increase precision.

Figure 63: Prototypes emerged from the research process.

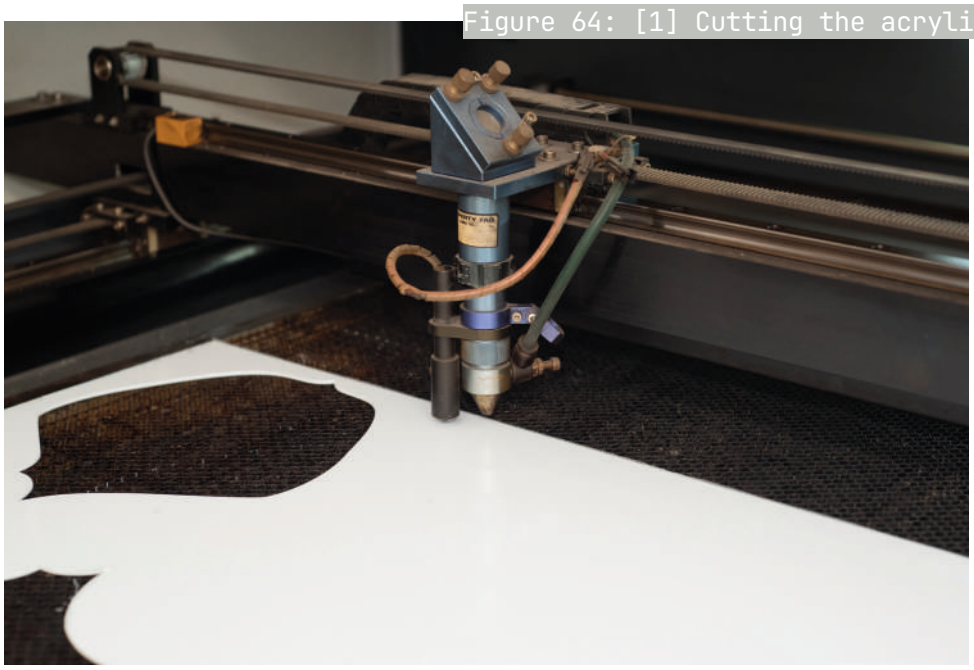
FINAL PROTOTYPING

The final prototyping process consists of:

1. CUTTING THE ACRYLIC: Initially, a piece of acrylic is cut following a reduced version of the internal geometry.
2. DEFINING THE GUIDE: Using the out-of-focus, low-power laser, a guide of the internal geometry is drawn, which is useful for positioning the acrylic correctly.
3. FIXING THE ACRYLIC: The acrylic is then fixed firmly to the cutting plane using magnets, ensuring a secure fit.
4. DOUBLE WELDING: Welding is carried out twice with a slight external offset to reinforce the seal.
5. EXTERNAL CUTTING: The laser, focused again, is used to outline and cut the external geometry of the acrylic
6. ASSEMBLY OF ADDITIONAL COMPONENTS: After removing the frame from the machine, the diffuser and tap are integrated. These components are housed inside rigid tubes, which are then inserted into their respective openings.

	FOCUS	SPEED	POWER	CORNER	OFFSET
TAGLIO ACRILICO	AF	15mm/s	30%	28%	-10mm
DEFINIZIONE GUIDA	60mm	26mm/s	9.5%	9%	-
DOPPIA SALDATURA	60mm	26mm/s	12%	6%	-
TAGLIO ESTERNO	AF	27mm/s	11%	9%	+4mm

Figure 64: [1] Cutting the acrylic.



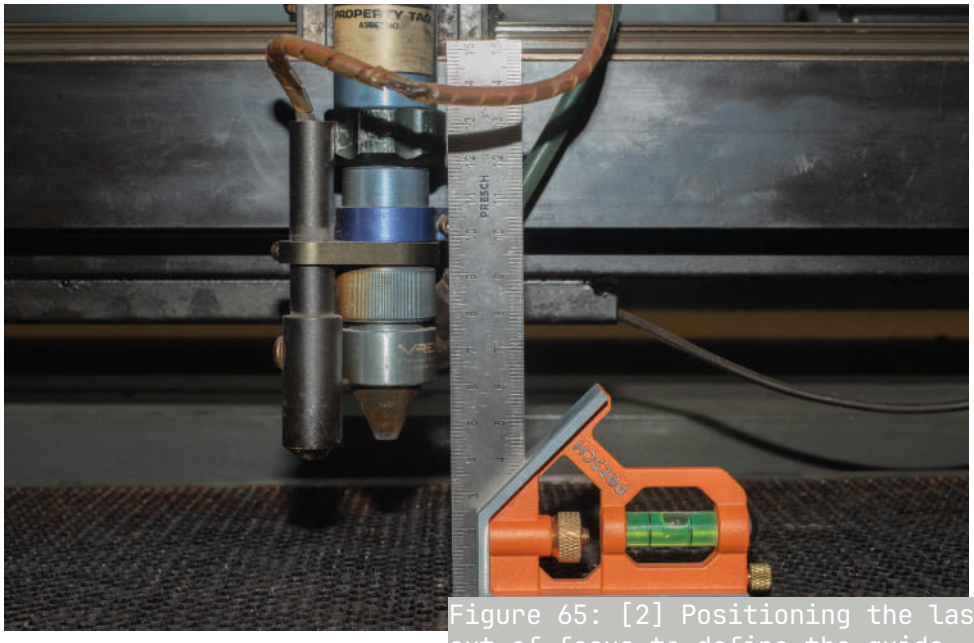


Figure 65: [2] Positioning the laser out of focus to define the guide.

Figure 66: [3] Fixing the acrylic.

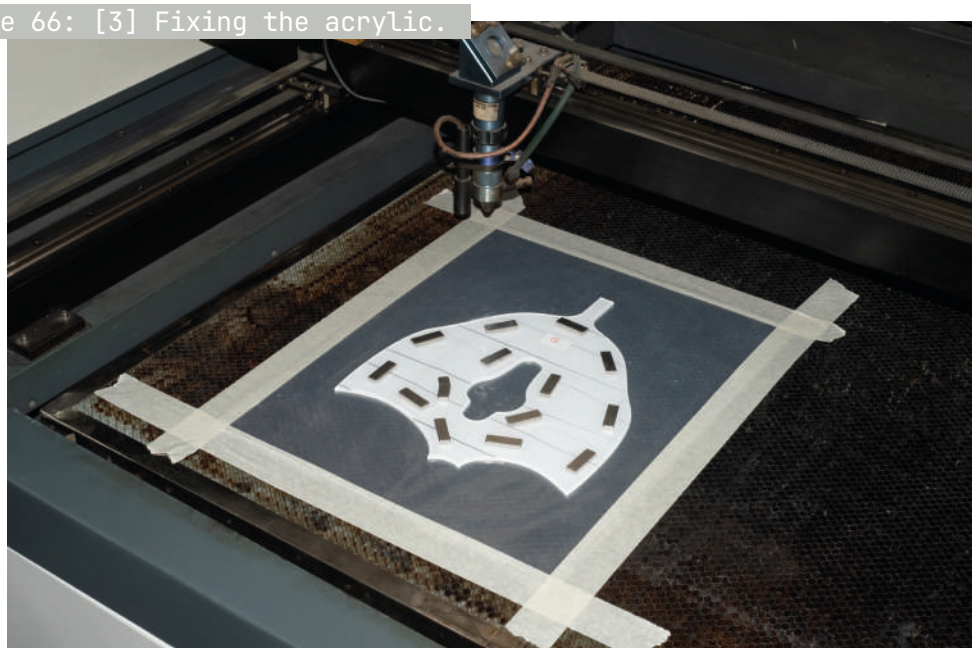
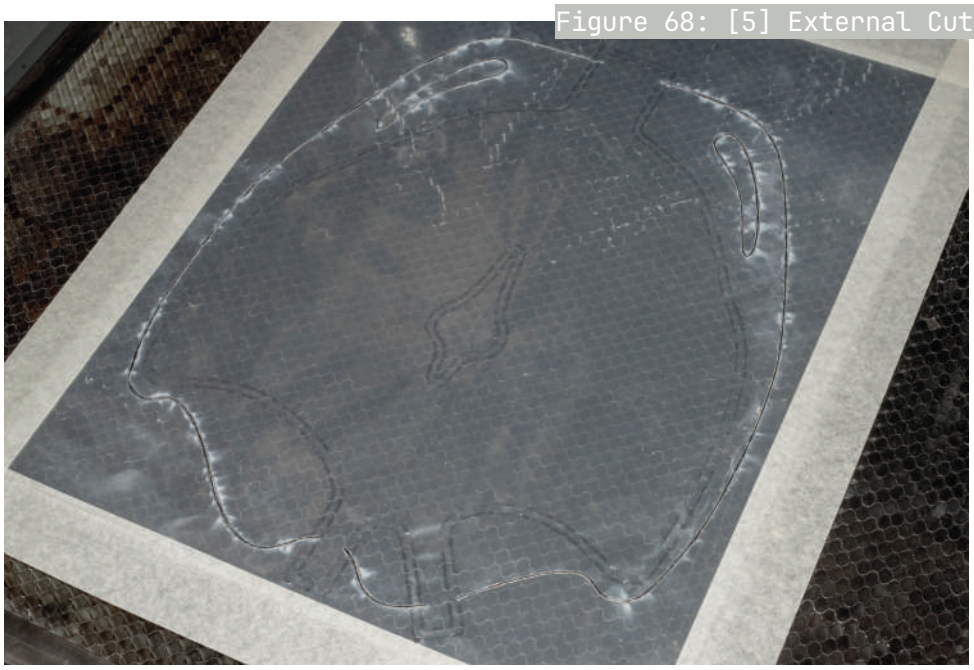


Figure 67: [4] Double welding.

Figure 68: [5] External Cutting.



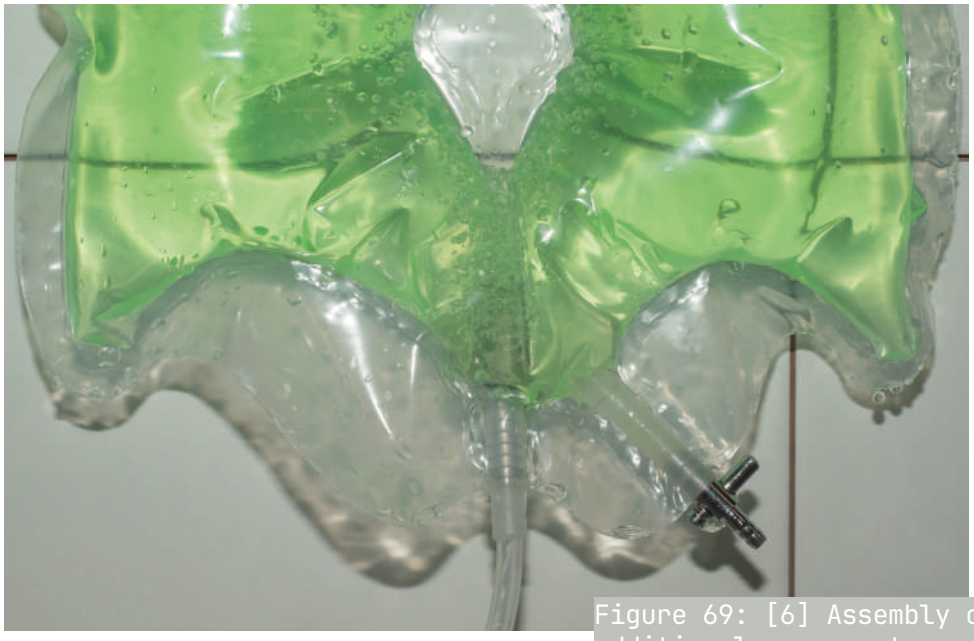


Figure 69: [6] Assembly of additional components.

Fig. 70-71: The final prototypes assembled in the laboratory.

04.5 IDENTITY

NAMING

During the development phase of the project, the respective considerations regarding its identity also emerged.
The name SPIRA was therefore chosen, inspired by the scientific terminology of Spirulina, known as Arthrospira Platensis. In its original taxonomy, 'spira' refers to the distinctive spiral shape of this microorganism.
Within the project, SPIRA not only represents the intention to make this field accessible outside the scientific context, but also the poetic essence of the term, evoking the act of breathing, a gesture shared by living beings breathing the same atmosphere.

VISUAL IDENTITY

To appropriately embody the essence of SPIRA, it was selected a logotype based on the SIRAP typeface by Rémi Volclair, a graphic designer and art director known for embodying organic forms in his aesthetics.
Alongside the logotype, a distinctive visual identity with a slightly ironic tone was developed.
The monochromatic grey-green colour, chosen as the background for SPIRA, departs from the representations of nature driven by vivid greens that often portray an idealised vision, in some cases becoming instruments of 'greenwashing'.

Instead, the complementary graphic approach draws inspiration from the aesthetics of the Frutiger Aero of the early 2010s, which represented a vision of the future infused with optimism, eco-friendliness and cutting-edge technology. In SPIRA, the intention is to evoke that ethereal vision, asking: where has the future we dreamt of gone?

#808b81
C:51 M:33 Y:44 K:16
R:128 G:139 B:129

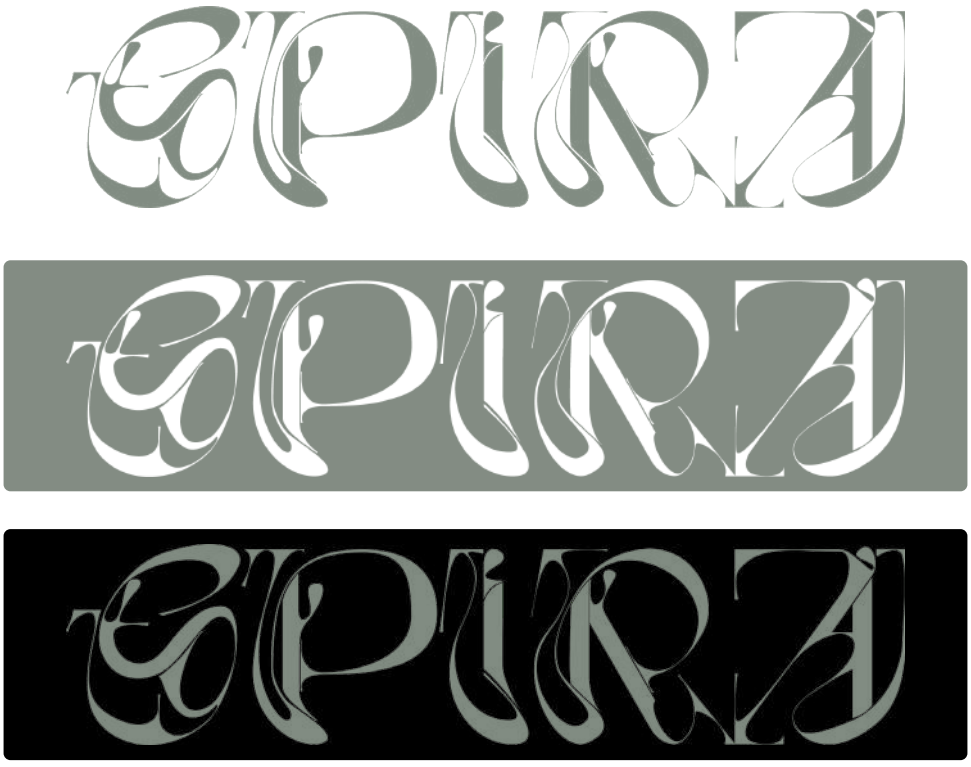
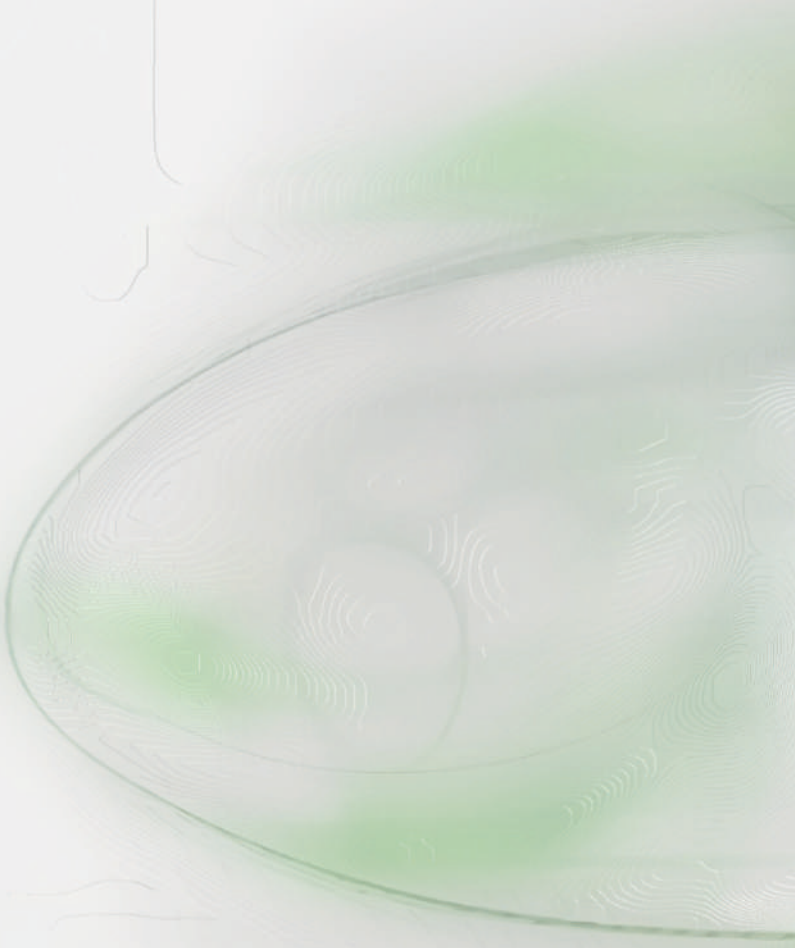
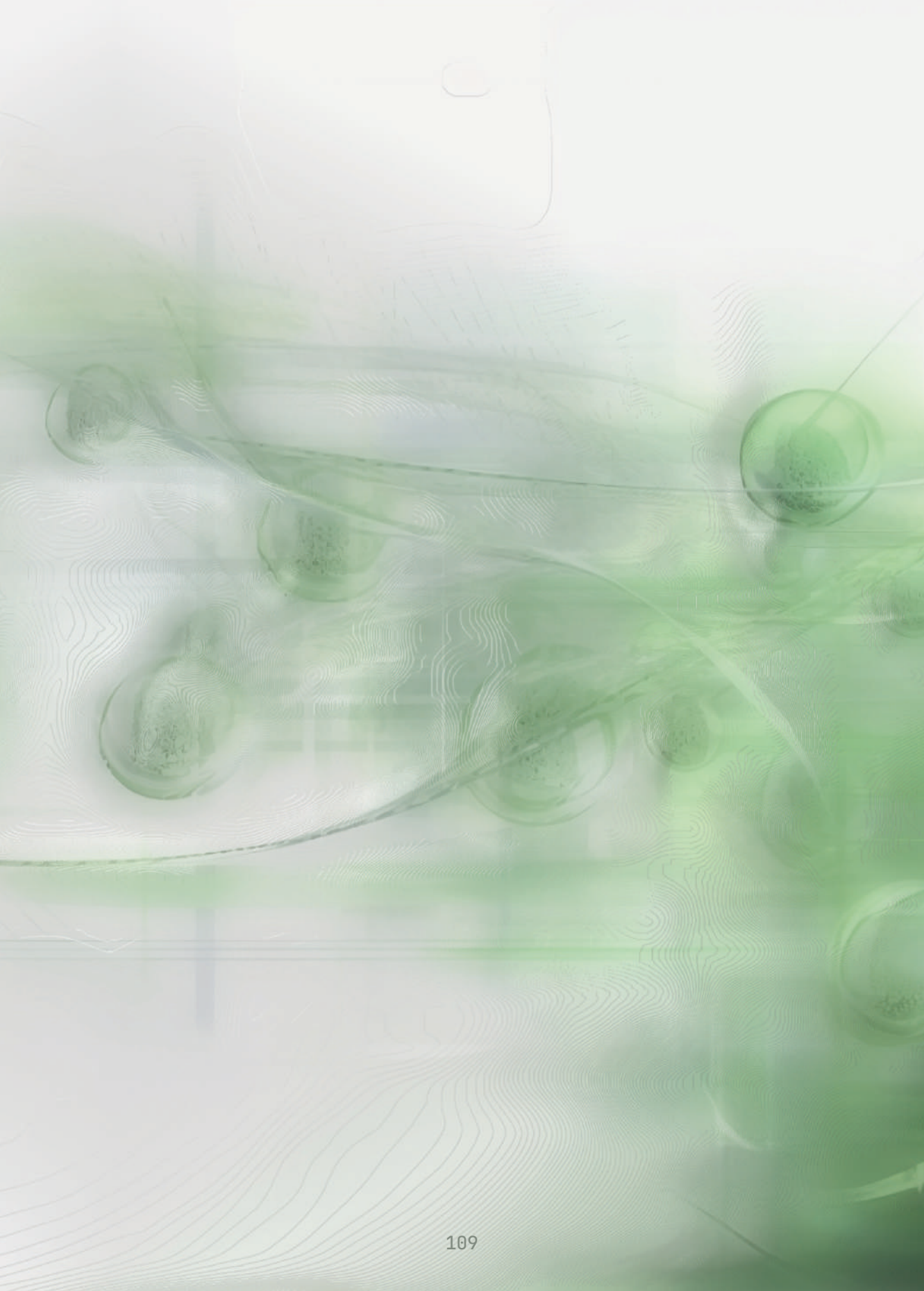


Figure 72: SPIRA logotype combined with its palette.

05. CONCLUSIONS





05.1 CRITICALITY

In SPIRA, ecological impact has always been placed at the centre of every design decision. However, working in the field of sustainability involves a deep sense of responsibility and the emphasis on meticulously examining every aspect. For a tool to be truly carbon negative, especially on a large scale, it is essential to undertake meticulous analysis.

In these terms, it would be essential to conduct a detailed LCA (Life Cycle Assessment) to quantify exactly how much carbon is required to produce and verify the disposal of the product. To strive for long-term results, a crucial study concerns the selection and origin of the materials used, particularly for electronic components. In fact, it is imperative to investigate not only the origin of the components, but also their durability and reliability over time.

At present, the toolkit is powered by the wall plug, making it dependent on energy consumption which, although minimal, often comes from non-renewable sources. One strategy to increase the eco-efficiency of the toolkit could be the integration of solar panels combined with an MFC (Microbial Fuel Cell) - a biological battery free of toxic materials. Although this remains an area of open experimentation, such a combination could transform the toolkit into a bio-artificial hybrid device capable of significantly reducing CO2 emissions in the long term.

However, it is essential to emphasise that the effectiveness of the toolkit in absorbing CO2 mainly occurs in confined environments, such as domestic or office spaces.
Therefore, optimising the ecological impact of the production

process becomes crucial in order to achieve more units and increase the value of the project as a whole. Regarding production, although the use of LDPE waste sheet is less impactful than other production methods, it is still a plastic material that is difficult to dismantle. Also, laser processing, although in minimal quantities, requires the use of CO2 to complete the welding process that is key in the creation of the photobioreactor.

It is essential to continue to explore and research materials of organic origin that facilitate the disposal of the products we use.
Such an analysis, combined with collaboration with biological entities such as microalgae, could help us rethink design, with a more ecocentric approach as a priority.

05.2 FUTURE SCENARIOS

SPIRA leaves ample opportunity for expansion for possible future developments. SPIRA's toolkit format offers flexibility in design, allowing for various expansions and variations.

In fact, it is possible to imagine more advanced toolkits equipped with additional tools, such as a color sensor to track the health of microalgae through changing shades of green, sending notifications to the user through their account. In addition, pH control components such as salts and litmus paper could be introduced, as well as an increase in the number of photobioreactors, microalgae and associated nutrients.

From a manufacturing point of view, an intriguing innovation could involve the use of bioplastic derived from microalgae to make the photobioreactor itself. This practice would exemplify a circular economy cycle, in which the microalgae become both the product and the container.

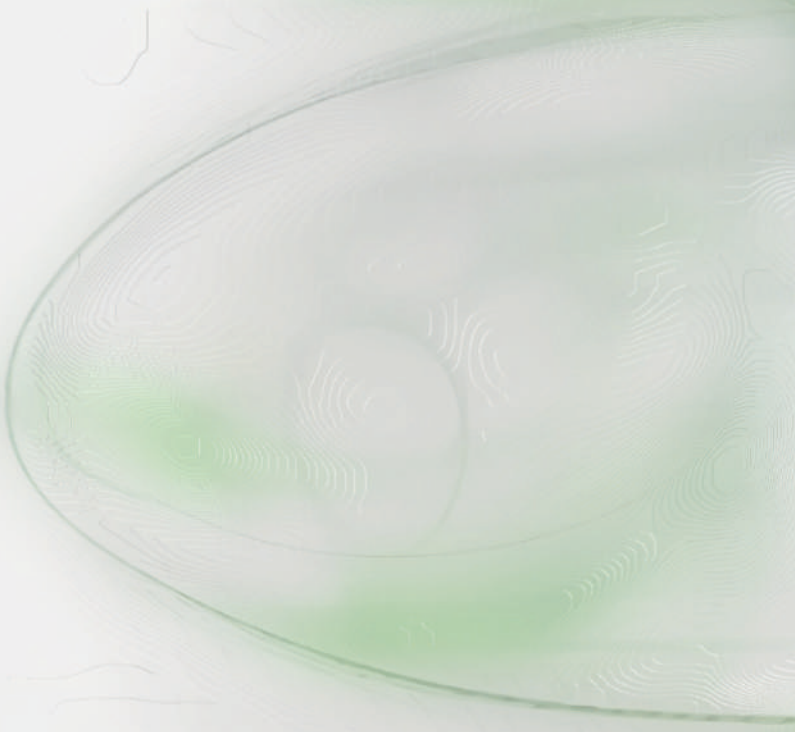
The communication side offers further opportunities.
By expanding its online presence, through its website and social channels, SPIRA could become a reference point for information, curiosities and guides on microalgae. The aim is to reach a wide audience, encouraging a community of enthusiasts and professionals to share experiences and advice.

The relationship between microalgae and design is still largely unexplored territory, rich in opportunities especially in the urban context. Considering the high CO2 levels in urban areas, microalgae photobioreactors could be strategically placed as temporary or permanent installations in places such

as building façades, roundabouts, intersections, tunnels or street lamps. These devices, if equipped with sensors, could create an interconnected urban network, with efficiency distributed on a large scale rather than centralised. A plausible example could see photobioreactors connected to organic waste collection points, exploiting the high CO2 emissions during decomposition to feed the microalgae. In this way, the waste could actively contribute to air purification and biomass generation.

In the contemporary and future landscape, the intersection of design, art and science remains one of the most stimulating creative symbioses. Science, with its incessant investigation of reality and its ability to explore and innovate, provides artists and designers with new materials, tools and perspectives. Similarly, design and art can interpret and depict these concepts in tangible and accessible ways, disseminating them more broadly in the social fabric. This kind of intersection not only leads to the creation of cutting-edge works or products, but also involves cultural discourse, stimulating society to reflect and interact with complex issues through aesthetic experience.

06. BIBLIOGRAPHY



06. BIBLIOGRAPHY

1. Morton, T. (2018). *Iperoggetti*. NERO.

2. Maldonado, T. (1971). *La speranza progettuale: ambiente e società*. Einaudi.

3. Papanek, V. (2019). *Design for the real world*. Thames & Hudson.

4. Morton, T. (2022). *Humankind. Solidarietà ai non umani*. NERO.

5. De Giuli, M., & Porcelluzzi, N. (2021). *Medusa. Storie dalla fine del mondo (per come lo conosciamo)*. NERO.

6. Valenti, A., & Pasquero, C. (2021). *The second life of micro-organisms. Bio-digital design for a new ecology of space and behaviour*. 9, 42-53. https://doi.org/10.19229/2464-9309/942021

7. Page, J. (2021). *Decolonizing science in Latin American art*. UCL Press.

8. https://www.gp-award.com/en/produkte/phytosphere

9. https://www.photosynthetica.co.uk/biobombola

10. Pasquero, C., & Poletto, M. (2023). *Biodesign in the age of artificial intelligence: Deep Green*. Taylor & Francis.

11. https://www.softrobotics.io/

12. https://news.mit.edu/2016/oxygen-first-appearance-earth-atmosphere-0513

13. Cadoret, J.-P., Garnier, M., & Saint-Jean, B. (2012). *Microalgae, Functional Genomics and Biotechnology. In Advances in Botanical Research* (Vol. 64, pp. 285-341). Elsevier. https://doi.org/10.1016/B978-0-12-391499-6.00008-6

14. https://encyclopedia.pub/entry/22579

15. https://www.bbc.com/travel/article/20210111-how-mexico-is-reclaiming-spirulina

16. Bridle, J. (2019). *Nuova era oscura*. NERO.

17. https://gml.noaa.gov/ccgg/trends/graph.html

18. https://www.carbonbrief.org/analysis-global-co2-emissions-from-fossil-fuels-hit-record-high-in-2022/

19. https://climateprimer.mit.edu/climate-change

20. Ali Maghzian, Alireza Aslani, & Zahedi, R. (2022). *Review on the direct air CO2 capture by microalgae: Bibliographic mapping*. Energy Reports, 8, 3337-3349. https://doi.org/10.1016/j.egyr.2022.02.125

21. Blair, M. F., Kokabian, B., & Gude, V. G. (2014). *Light and growth medium effect on Chlorella vulgaris biomass production.* Journal of Environmental Chemical Engineering, 2(1), 665-674. https://doi.org/10.1016/j.jece.2013.11.005

22. Legrand, J., Legrand, J., Artu, A., & Pruvost, J. (2021). *A review on photobioreactor design and modelling for microalgae production.* Reaction Chemistry and Engineering, 6(7), 1134-1151. https://doi.org/10.1039/d0re00450b

23. Deprá, M. C., Severo, I. A., Dias, R. R., Zepka, L. Q., & Jacob-Lopes, E. (2021). *Photobioreactor design for microalgae culture.* 35-61. https://doi.org/10.1016/b978-0-12-821218-9.00002-5

24. Khan, M. I., Shin, J. H., & Kim, J. D. (2018). *The promising future of microalgae: Current status, challenges, and optimization of*

06. BIBLIOGRAPHY

a sustainable and renewable industry for biofuels, feed, and other products. Microbial Cell Factories, 17(1), 36–36. https://doi.org/10.1186/s12934-018-0879-x

25. Elrayies, G. M. (2018). *Microalgae: Prospects for greener future buildings*. Renewable & Sustainable Energy Reviews, 81, 1175–1191. https://doi.org/10.1016/j.rser.2017.08.032

26. Valenti, A., & Pasquero, C. (2021). *The second life of micro-organisms. Bio-digital design for a new ecology of space and behaviour*. 9, 42–53. https://doi.org/10.19229/2464-9309/942021

27. Farida, H., Harahap, P. S., Sobari, R., Gunawan, R., Rahman, D. Y., & Susilaningsih, D. (2019). *Outdoor Closed System of Algal Mass Culture: In Sight of Comparison on Vertical and Horizontal Photobioreactor for Cultivating the Spirulina sp*. Reaktor, 19(2), 54–61. https://doi.org/10.14710/reaktor.19.2.54-61

28. Dineshkumar, R., Narendran, R., & Sampathkumar, P. (s.d.). *Cultivation of Spirulina platensis in different selective media*.

29. https://www.instructables.com/Laserweld-Your-Own-Inflatables/

30. https://www.transmediaresearch.institute/summer-school-2023/biofabricated-soft-robots-and-inflatables